Final Report

Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra: Maharashtra State Adaptation Action Plan on Climate Change (MSAAPC)

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Executive Summary

1. Introduction

In 2008, the Government of India released the National Action Plan on Climate Change (NAPCC), and in August 2009, directed the States to develop State Action Plans on Climate Change guided by and consistent with the structure and strategies of the NAPCC. The Government of Maharashtra took a pioneering step towards formulating the Maharashtra State Adaptation Action Plan on Climate Change (MSAAPCC) by commissioning a comprehensive vulnerability assessment study which included the task of generating model-based climate projections specific to the State's geography. The Government of Maharashtra appointed The Energy and Resources Institute (TERI) in 2010 to carry out this study, titled "Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra", which broadly aimed to "address the urgent need to integrate climate change concerns into the State's overall development strategy, thus assisting in building long term climate resilience and enabling adaptation to the likelihood of risks arising from climate change". The study outputs have been used to formulate the Maharashtra State Adaptation Action Plan on Climate Change (MSAAPCC).

2. Methodology

This study combined a rigorous methodology with a strong consultative process, with the following steps:

1. High resolution climate change modelling for Maharashtra
2. Sector-specific assessment of climate change impacts for priority sectors and cross-sectoral issues
3. Identification of state-level sector-specific adaptation strategies
4. District-level vulnerability index development and identification of six vulnerability hotspot districts
5. Quantitative household-level surveys with farming and fishing households in six vulnerability hotspot districts
6. Detailed stakeholder consultations and preparation of district-level adaptation action for six vulnerability hotspot districts and Mumbai Metropolitan Region
7. Validation of findings and discussion of adaptation strategies with state line departments and district administration.

For the modelling component, TERI entered into a partnership with the UK Met Office in 2010 to assist in the development of climate projections for the State as a unit. Using the high resolution HadRM3P model in the PRECIS Regional Climate Modelling System and a unique domain1 selection method that sought to represent the climatic pattern over the state's topography to a fairly good degree, changes in temperature and rainfall were projected at a resolution of about 25 km x 25 km.

These projections related to three future time slices during the 21st century – 2030s, 2050s, and 2070s, with respect to the model baseline, which was the average climate during 1970-2000. The model results were validated using several observational datasets including those

[1] Domain refers to the grid or region over which the climate model is run. Three domains were tested and the optimum domain selected which provided the closest representation of inter-annual variability in both precipitation and temperature.

of the India Meteorological Department (IMD). The four priority areas considered for further assessments include the following:

(a) Hydrology & fresh water resources

(b) Agriculture & food systems

(c) Coastal areas marine ecosystem and biodiversity and

(d) Livelihood (including migration and conflict).

Additionally, some cross-cutting areas were identified including issues related to human health, ecosystem and biodiversity, markets, and risk management.

Based on the sector and cross-sectoral impact and vulnerability assessments and taking account of the regional diversity within the state, the study developed key recommendations for the selected sectors along with implementable adaptation measures. An important component for this included the development of a Macro Level Vulnerability Index (MLVI), which identified the most vulnerable districts in the state. The MLVI comprised of 19 indicators under the categories of exposure, sensitivity and adaptive capacity to assess the vulnerabilities of the districts. The corresponding data specific for all the districts was analysed to develop the index. . A ranking exercise was undertaken for the districts on the basis of the vulnerability index which ranked Nandurbar as the most vulnerable district, followed by Dhule and Buldhana. Satara was regarded as the least vulnerable district, whereas Ratnagiri and Sindhudurg were also considered less vulnerable as compared to other districts. To validate and ground-truth the climate sensitivity, exposure levels, and adaptive capacity of communities to climate change and extremes, six vulnerability hotspots were selected for in-depth case studies and local-scale consultations (Table 1). In addition, the Mumbai Metropolitan Region was selected for a detailed case study due to its economic and demographic significance for the state. These case studies represent the range of climatic zones, socio-economic diversity, and administrative divisions in Maharashtra.

Table 1. Case study district representing various divisions

Administrative division	Case study district
Amravati	Buldhana
Aurangabad	Hingoli
Nashik	Nandurbar
Nagpur	Gondia
Pune	Solapur
Konkan	Thane

A detailed quantitative household-level survey was carried out with 1538 rural households in these six districts to elicit their perceptions about climatic changes, to understand the factors contributing to their vulnerability, and to identify their adaptation needs.

Extensive stakeholder consultations were carried out with local communities, panchayats, block-level officials, and district officials in these six districts and the Mumbai Metropolitan Region to discuss and validate the climate modelling results, climate change impacts, and key vulnerabilities, and to identify the most appropriate adaptation measures through a participatory approach. District level action plans were drafted for all the case study districts based on extensive stakeholder consultations.

3. Climate change projections

Climate change projections for Maharashtra were developed after following a process of domain selection and validation of the model outputs with observations. The domain having a higher correlation with observations was then chosen for future projections. The methodology so followed for domain selection and model runs was unique to the state of Maharashtra. Based on this unique domain selection method that sought to represent the regional climate over Maharashtra to a fairly good degree, rainfall and temperature changes have been projected for three time slices- 2030s, 2050s and 2070s.

Figures 1 and 2 present the projected increases in mean temperature and average monsoon rainfall over Maharashtra. These projections are also summarized by administrative division in Table 2.

The climate modelling results show that temperature and rainfall are projected to increase all over the state though there are regional variations. Over time, the projected rise in mean temperature is greater for the 2070s (Figure 1c) compared to the 2050s (Figure 1b) and the 2030s (Figure 1a). Amravati and Aurangabad divisions may experience a greater rise in annual mean temperature than other parts of the state. The projected increase in monsoon rainfall by the 2030s (Figure 2a) and 2050s (Figure 2b) is relatively more for Amravati and Nashik divisions, though divisions like Konkan and Nagpur receive, and are projected to continue to receive, more rainfall in absolute terms. This overall increase in monsoon rainfall for the state is consistent with the findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)[2]. The full set of district-wise projections is presented in Appendix 1.

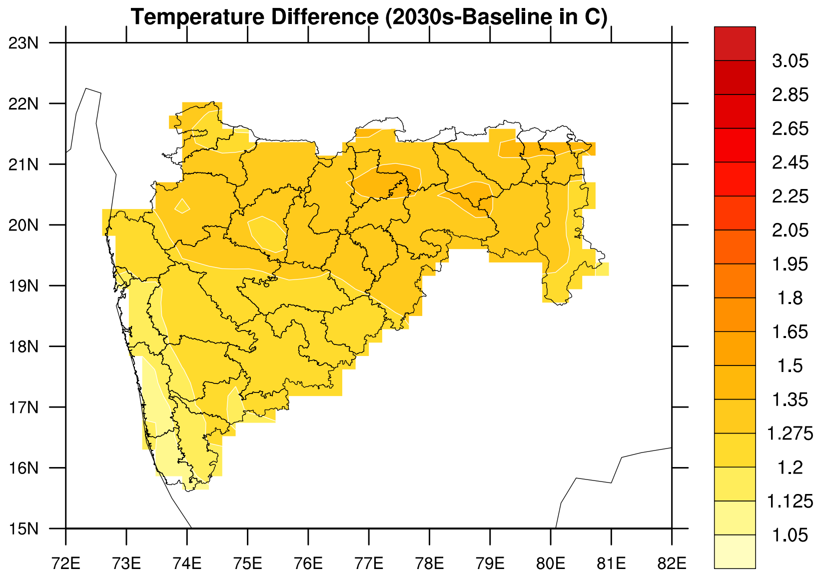
Table 2. Division wise climate change projections

Administrative division	IMD climate normal: annual mean temperature (ºC)	Projected increase in annual mean temperature (ºC)			IMD climate normal: monsoon rainfall (mm)	Projected increase in monsoon rainfall (%)		
		2030s	**2050s**	**2070s**		**2030s**	**2050s**	**2070s**
Amravati	27.21	1.44-1.64	2.2-2.35	3.06-3.46	785.3	17.5-30	22.5-32.5	15-27.5
Aurangabad	26.46	1.44-1.56	2.15-2.3	3.14-3.38	708.8	12.5-27.5	15-30	20-40
Nashik	26.79	1.4-1.68	2-2.4	2.82-3.3	567.5	17.5-40	15-40	15-52.5
Nagpur	27.19	1.18-1.4	1.95-2.2	2.88-3.16	1124.7	12.5-20	12.5-30	15-27.5
Pune	25.22	1.15-1.28	1.65-1.95	2.46-2.74	852.2	10-32.5	10-32.5	12.5-37.5
Konkan	26.99	1.1-1.28	1.5-1.8	2.18-2.6	2578.2	10-30	10-30	10-32.5

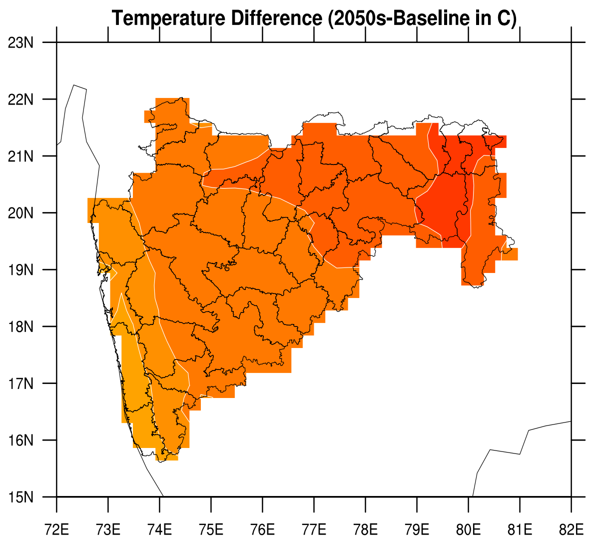
Note: The projection for the 2030s is the average of projections for the period 2021-2040. Similarly, the projection for the 2050s in the average of projections for 2041-2060 and that for the 2070s is the average of projections for 2061-2080.

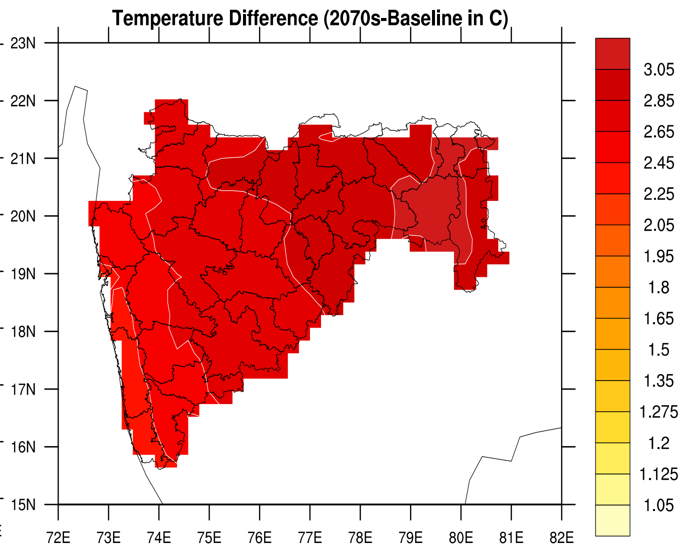
[2] IPCC Working Group 1 Technical Summary Section TS.5.8.1 and Table TS.2

Figure 1. Projected increase in temperature over Maharashtra in the (a) 2030s (b) 2050s (c) 2070s relative to the baseline (in degree Celcius)



(a)

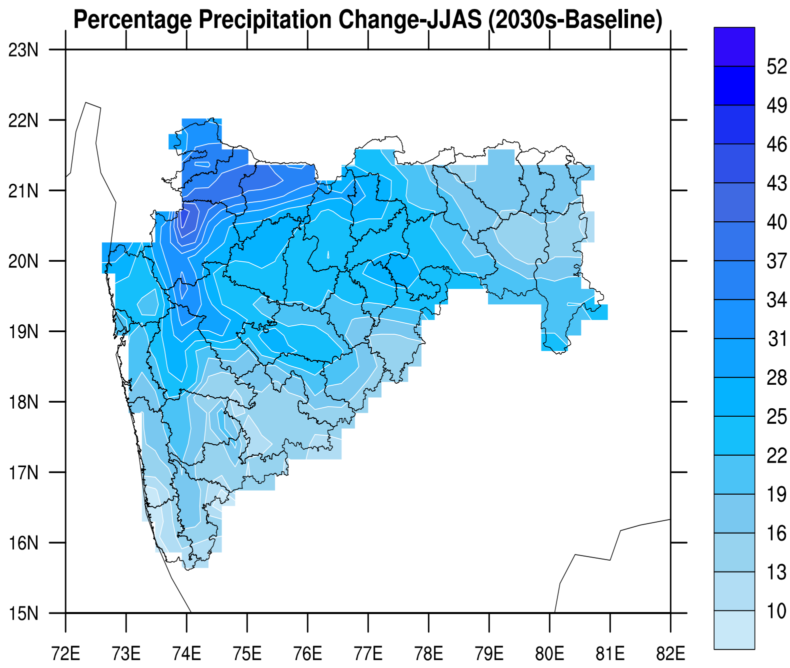




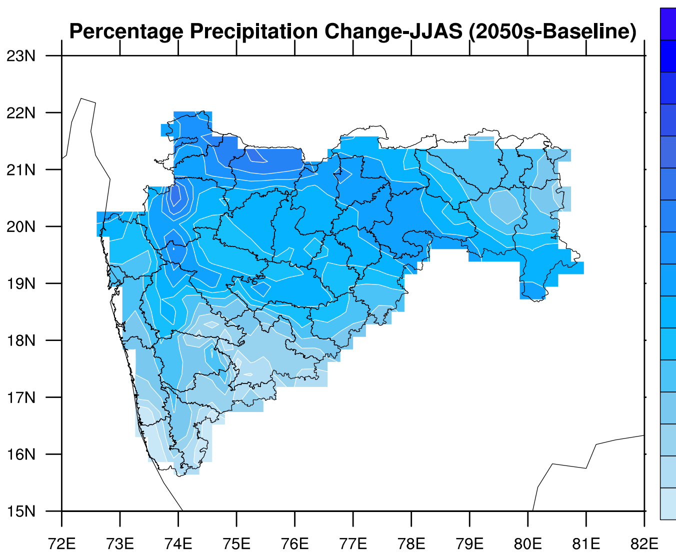
(b)

(c)

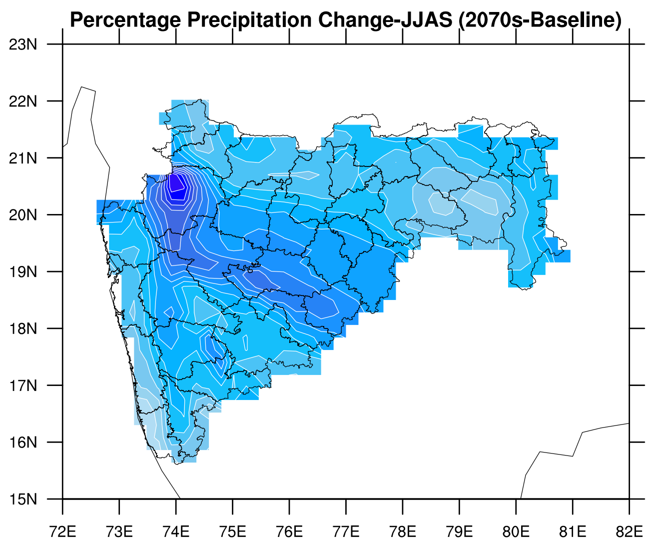
Figure 2. Projected increase in precipitation over Maharashtra in the (a) 2030s (b) 2050s (c) 2070s relative to the baseline (in per cent)



(a)



(b)

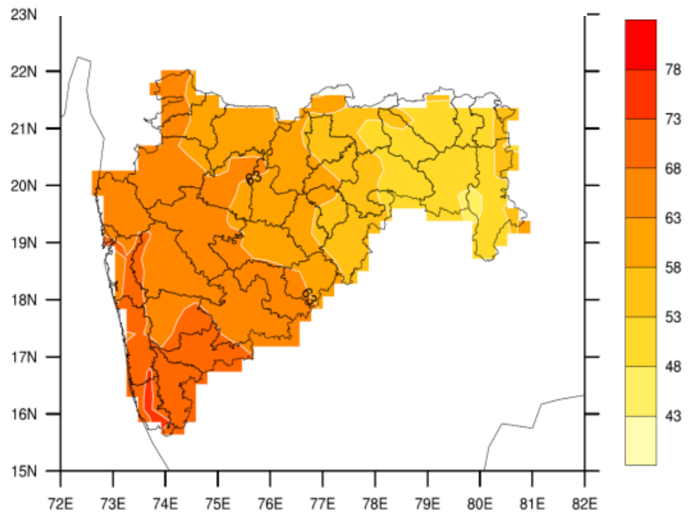


(c)

Using the climate model results, climate change indices[3] of extreme heat and extreme rainfall were computed for each grid of 25 km x 25 km in Maharashtra.

Though Table 2 gives the increase in mean temperature, the projected rise in minimum temperature is more than the projected rise in maximum temperature. Figure 3 shows that the minimum temperature is projected to increase particularly in the Konkan, Pune and Nashik divisions in the 2030s relative to the baseline for these areas. This could have an adverse impact on crops that are sensitive to high night temperatures in the reproductive phase, e.g. grain growth in rice or tuberization in potatoes.

Figure 3. Projected increase in minimum temperature in 2030s relative to the baseline (in per cent)[4]



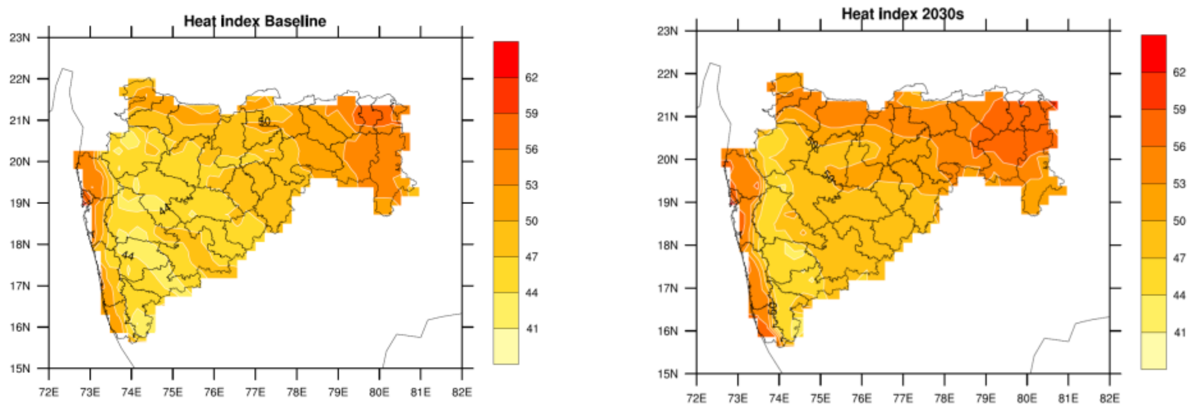
Projected increase in minimum temperature	Indicative areas
73 – 78	Parts of Sindhudurg
68 – 73	Ratnagiri, Kolhapur, Sangli, and parts of Mumbai, Raigad, Sindhudurg, and Satara
63 – 68	Nashik, Ahmednagar, Thane, Pune, Solapur, Osmanabad, Nandurbar, Aurangabad, and parts of Dhule, Satara, Beed, Latur, Mumbai and Raigad
58 – 63	Jalgaon, Budhana, Jalna, Parbhani, and parts of Dhule, Beed, Latur, Washim and Hingoli
53 – 58	Akola, Nanded, and parts of Amravati, Yavatmal, Washim and Hingoli
48 – 53	Nagpur, Bhandara, Gondia, Gadchiroli, Chandrapur, Wardha, and parts of Yavatmal and Amravati

Figure 4 shows the heat index which is computed by combining projections for air temperature and relative humidity to indicate human comfort levels. An increase is

[3] As recommended by the Expert Team on Climate Change Detection and Indices - a global team of climate change scientists under the World Climate Research Programme which has recommended indices to understand extreme events.
[4] It is calculated as per cent of days in future where minimum temperature exceeds 90% of its baseline value (for each grid point).

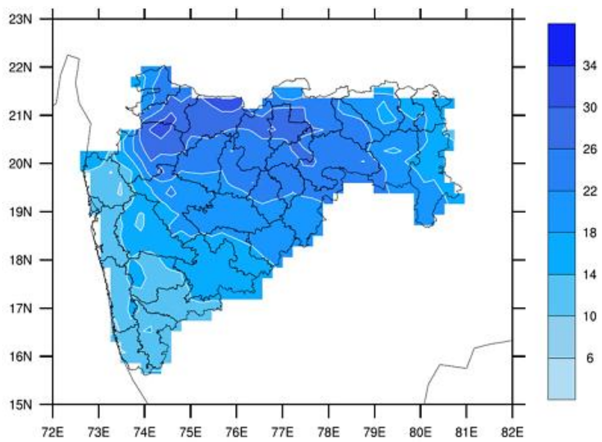
projected for Konkan and Nashik divisions by the 2030s relative to the baseline for these areas. This may increase human discomfort due to heat stress and also increase the number of days that are conducive to malaria parasite development and transmission. It may also increase the energy demandf or cooling in urban areas that are already experiencing the urban heat island effect.

Figure 4. Projected increase in heat index in 2030s relative to baseline (in degree Celcius)



A warmer atmosphere has a higher capacity to hold water. This is likely to produce more intense rainfall events with longer dry or low rainfall spells between these events. Figure 5 shows that extreme rainfall is projected to increase in all regions with greater increases in the northern parts of the state (Aurangabad and northern regions of Nashik division)[5].

Figure 5. Increase in extreme rainfall in 2030s relative to baseline (in %)



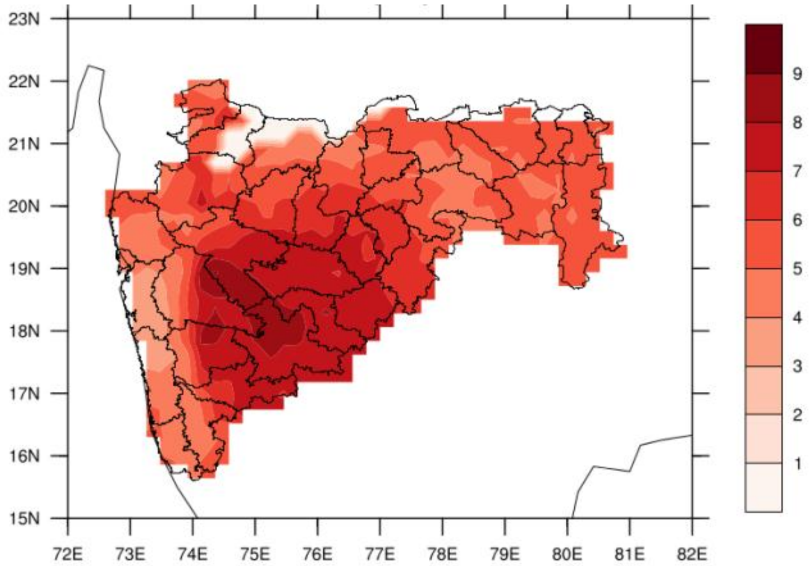
Projected percentage increase in extreme rainfall in 2030s relative to baseline	Indicative areas
More than 30	Parts of Jalgaon, Dhule and Nashik
26 – 30	Jalgaon, Dhule, Nashik, Akola, and parts of Buldhana and Washim
22 – 26	Amravati, Yavatmal, Hingoli, Jalna, and parts of Aurangabad, Buldhana, Parbhani, Washim, Wardha, Nanded, Nandurbar, and Nashik

[5] Extreme rainfall in future is calculated as future rainfall which is greater than 99% of rainfall intensity in the entire baseline period at each grid point.

18 – 22	Nagpur, Chandrapur, Nanded, Latur, Beed, Ahmednagar, and parts of Parbhani, Gadchiroli, and Nandurbar
14 – 18	Pune, Solapur, Osmanabad, Gondia, Bhandara, and parts of Gadchiroli
10 – 14	Thane, Mumbai, Ratnagiri, Sindhudurg, Kolhapur, Sangli, and Satara

Figure 6 shows the projected number of extremely low rainfall days in the June-August monsoon months in the 2030s[6]. Parts of south central Maharashtra are projected to experience more dry days in the 2030s relative to the baseline for this region. This is a matter of concern for agriculture and water resources in this region.

Figure 6. Number of low rainfall days in the 2030s relative to baseline



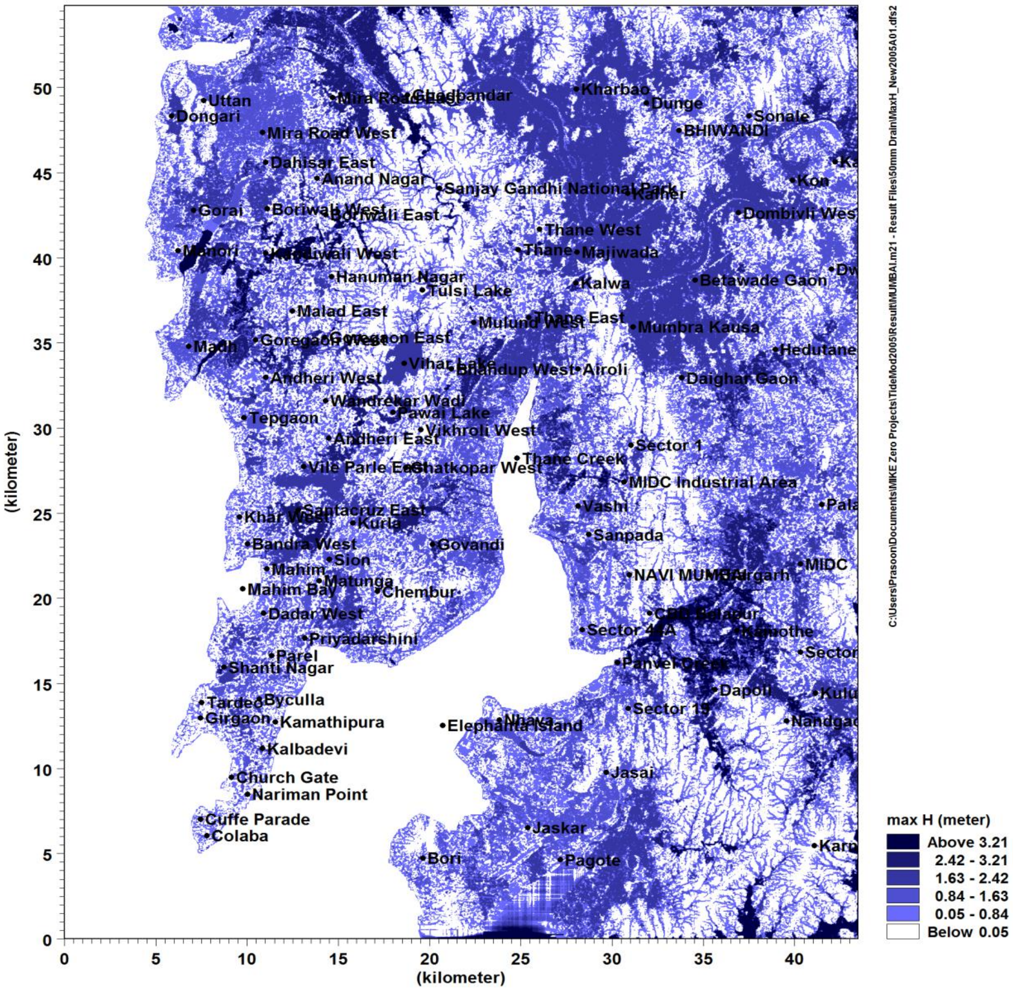
Projected increase in number of dry days (in 2030s relative to baseline)	Indicative areas
8 – 9	Parts of Ahmednagar and Solapur
7 – 8	Beed, Latur, Osmanabad, and parts of Solapur, Ahmednagar, Sangli, Satara, Pune, Parbhani and Jalna
6 – 7	Nanded, Hingoli, and parts of Buldhana, Jalna, Aurangabad, Ahmednagar, Nashik and Sangli
5 – 6	Gadchiroli, Gondia, Bhandara, Nagpur, Akola, Washim, and parts of Amravati, Chandrapur, Wardha, Yavatmal, Budhana, Auranagabd, Nashik, Nandurbar
4 – 5	Thane, Mumbai, and parts of Ratnagiri, Sindhudurg, Kolhapur, Jalgaon, Yavatmal
3 – 4	Raigad and parts of Ratnagiri
0 – 3	Parts of Dhule and Jalgaon

To identify areas in Mumbai Metropolitan Region that are prone to flooding when exposed to heavy rainfall events, flood maps were generated for different rainfall events. These maps simulate the rainflow and water level variations, using satellite imagery and rainfall data. They consider tidal vairations since the drainage system is overloaded during high tide.

[6] Extremely low rainfall days are computed as days with rainfall less than 1% quantile for June-August months at each grid point.

These maps were validated using the observed data sets from the disaster management reports of the Municipal Corporation of Greater Mumbai. Figure 7 shows the areas that would be flooded even at an augmented drainage capacity of 50 mm/hour if an extreme rainfall event like that of July 2005 were to recur.

Figure 7. Water Depth Map of Mumbai Metropolitan Region



Note: For extreme rainfall event of 2005 with tide variation and drainage capacity of 50 mm/hr rainfall

Water depth (in metres)	Locations
0.05 – 1 m	Several pockets of Colaba, Parel, Bandra, Fort, Byculla, Dadar, Milind Nagar, Marol, etc
1 – 2 m	Chhatrapati Shivaji International Airport; Railway Colony, Badhwar Park, Apollo Bandar, Colaba; Ballard Estate, Fort; Null Bazar, Kamathipura, Saat Rasta Maulana Azad Road, Jacob Circle, Chinchpokli, Nirmal Park Railway Colony, Lower Parel West, Mahim Junction to Matunga Road, Mahalaxmi Sindhi Colony, Matunga West; Friends Colony, Hallow Pul, Kurla West; Ali Yavar Jung, Premier Colony, Kurla West; Lokmanya Tilak Terminus, Kurla East, Mira Bhayandar
2 – 3 m	Ramabai Ambedkar Nagar, Bombay Port Trust Road, Panchsheel Jogger's Park, Old Collector Compound, BMC Colony, Manohar Nagar
3 – 4 m	Raje Shivaji Nagar, Sunder Pada, Kandivali West; Kandivali Police Line, Kandivali West; Near creeks

Sea level rise analysis was done for the Maharashtra coastline. Historical analysis of 100-year tide gauge data[7] and 17-year satellite data[8] showed a sea level rise of 0.13-2 cm. In the future, global mean sea level is projected to increase by 30 cm to 55 cm by the end of the 21st century for a medium range climate change scenario (RCP 4.5). Though there may be some regional variations, about 68% of the world's coastlines are projected to experience sea level rise of within ±20% of this range for this scenario. This corresponds to a range of about 24 cm to 66 cm for the Maharashtra coastline. Moreover, global models predict that this sea level rise could be accompanied by increase in wave heights, increase in wind speeds, and greater storminess and storm surge.

To strengthen the findings from the climate modeling and vulnerability assessment, stakeholder consultations were carried out at different levels including State, district and communities, in the selected six districts of Thane, Solapur, Nandurbar, Hingoli, Gondia and Buldhana. The following sections are a compilation of the assessments done and information collated through the stakeholder interactions.

4. Sector-specific Impacts, Recommendations and Action Plans

4.1 Agriculture

Impacts

- Increase in temperature is likely to lead to decrease in yields for some crops. Recent studies done by agricultural scientists indicate that an increase in temperature from 1 to 4 °C results in reduction in potential yield of crops. For instance in case of rice the drop can vary from 0 to 49%. A 1°C and 2.3°C rise in temperature results in 6.3% and 17.5% decline in sorghum yield in semi-arid conditions. 1 to 4 °C increase results in reduction in soybean yield of 11 to 36%. A temperature rise of 1.85°C may result in no significant change in cotton yield in central India, but a temperature rise of 3.2°C can lead to a 268 kg/ha decline in cotton yield.

- Increase in CO_2 concentration may lead to increases in yields in some crops to some extent. For example, recent experimental evidence shows that increases in CO_2 concentration up to 700 ppm may result in average yield increase of rice by 30% and an increase in 50 ppm CO_2, increases yields in sorghum by 0.5%. However, the beneficial effect of 700 ppm CO_2 in sorghum was nullified by a temperature increase of only 0.9°C. Free air CO_2 enrichment experiments on soybean show an almost 15% increase in yield due to elevation of carbon dioxide concentration to 550 ppm. While studies have found cotton production under elevated carbon dioxide level of 650 ppm and temperature of 40 degree centigrade to improve productivity, over time as temperature increases, the CO_2 fertilization effect gets nullified and the net effect on yields could be negative.

[7] From the Permanent Service for Mean Sea Level of the National Oceanographic Center (NOC) and the National Environmental Research Council (NERC)
[8] From the Archiving, Validation and Interpretation of Satellite Observational (AVISO) dataset of the National Oceanic and Atmospheric Administration of the United States

- Pest incidence may increase due to increase in rainfall. For example, the increasing trend in post monsoon season in Maharashtra may increase incidence of black mould in sorghum and of Heliothis in cotton and red gram, according to research by the Mahatma Phule Krishi Vidyapeeth.

- With the projected increase in precipitation, yield of rainfed crops could improve if the water resources are managed properly. The INCCA 4x4 Assessment showed that by the 2030s rain fed rice yields in the Western Ghats could range from -35% to +35% of current yields.

- Crop modeling results for the case study of rice production in Karjat station in Raigad district shows a projected increase of 33% in the potential yield of rice by the 2030s due to the projected increase in temperature and rainfall. After the 2030s, with further increase in temperature, the potential yield is projected to decline in successive decades but to a level that is still above the estimated yields in the baseline.

Key recommendations

- Farmer advisories by agricultural extension agencies on appropriate crops as temperature and rainfall patterns change and the suitability of climate for crops is altered.

- Research on high yielding varieties of hardy traditional crops (including summer crops, traditional early sowing rice variety like bhadas in Konkan) and promotion of heat-tolerant and early maturing varieties.

- Provision of frequent and localized weather forecasts and crop-specific agricultural advisories to encourage farmers to change cropping practices (e.g. delay sowing dates, protective irrigation). Denser networks of monitoring stations for better pest and disease surveillance and climate services.

- Measures to conserve soil moisture for winter and summer crops, and improved planning and construction of watershed management structures like percolation tanks and check dams.

- Improvement in post-harvest management and improved access to cold storage and warehousing with credit, subsidies, and training of farmers on good practices.

- Preservation of good agricultural land in peri-urban areas through designation of urban food zones around major cities to source the city's food (e.g. vegetables, milk, eggs), reduce its carbon footprint, and secure its food supply chain against climate risks.

Action plan

Safeguard farmers against climate risks through improved access to climate services, risk management strategies, and safety nets against climate extremes

- Expand the network of farmers with access to climate services and weather advisories, particularly small farmers. Disseminate information through Gram Panchayat-level knowledge hubs.

- Institute knowledge network of research institutions (IITM, IMD, Agriculture universities and Colleges and Research Stations) to develop integrate seasonal climate forecasts into decision support systems/ applications and provide localized and crop-specific agricultural advisories.
- Develop database of cultivars of important crops with features such as drought resistance, salinity tolerence, and pest resistance.
- Provide seeds for short duration and improved varieties of minor millets (e.g. ICRISAT varieties), intercropping with short duration red gram and soyabean, drought tolerant variety of Bengal gram (e.g. drought tolerant Digvijay variety of Bengal gram developed by the Mahatma Phule Krishi Vidyapeeth Rahuri).
- Increase allocation of funds to State Agricultural Universities for priority research on high yielding varities of heat-tolerant and drought-resistant crops.
- Develop a network of gene banks to exchange germplasm and establish good practices for maintaining gene bank base collection and seed vault (community level and at state level) and use for isolating resistant traits.
- Scale up mobile-based disease surveillance and institute forewarning system for emerging pests and pathogens in different agro-climatic zones, and provide customized advisories in partnership with agriculture universities, research stations, and private companies.
- Educate farmers through KVKs on likely changes in pests and pathogens under climate change scenarios and their prevention/treatment.
- Simplify and explain crop insurance to farmers and encourage the participation of non-loanee farmers. Increase access to livestock insurance. Extend the Modified National Agriculture Insurance Scheme to more villages and the Farmers Personal Accident Insurance Scheme to include more weather perils. Scale up pilot weather-based crop insurance schemes and expand the automated weather station network to provide accurate site-specific weather data.

Enhance resilience of farming systems through diversified cropping patterns, soil conservation, and value addition

- Promote diversification of cropping pattern to include hardy crops and adoption of integrated farming system approach. Advise farmers on sustainable and profitable farming systems (e.g. rice-fenugreek-okra and rice-onion-cowpea in heavy block soils) and sensitize them about the advantages of intercropping and crop diversification for climate change adaptation.
- Develop, demonstrate, and disseminate heat tolerant and short-duration varieties of pulses (esp. chickpea and pigeon pea) and high yielding varieties of millets. Similarly, promote heat-tolerant indigenous cattle breeds.
- Provide start-up funds for community-managed grain banks to supply good drought-resistant seeds and to maintain stocks for food and fodder security.
- Promote soil conservation by adopting international best practices of maintaining records of soil quality. Train farmers on precision farming techniques (e.g. fertilizer microdosing) to conserve water, soil, and nutrients.
- Extend the ongoing initiative to develop village-wise soil fertility index for major and micronutrients under the Rashtriya Krishi Vikas Yojana to develop village-level drought risk maps showing soil quality, irrigation availability, and zones where drought has greater impact on crops. Such maps can be developed for every village in a participatory manner and digitized in a GIS platform.

- Adopt a State Organic Farming Policy that promotes nutrient recycling on integrated livestock and cereal production farms and supports village-level production of organic manure for small farmers.
- Establish market linkages and branding for farmers cooperatives, e.g. with urban or export markets for organic produce, or with the poultry feed industry or health food manufacturers for millets.
- Promote summer crops such as summer maize to address security of food and especially fodder in drought prone areas of Marathwada region as well as districts like Solapur, Usmanabad, Amravati and Gadchiroli. This would enable development of dairy sector in areas like Dhule and Hingoli where livelihood diversification is needed.
- Train self help group networks on climate resilient livelihood options and market linkages. For example, goat-rearing and poultry-farming are more resilient to rainfall variability than buffalo rearing as they require less green fodder and water.
- Increase value addition through agro-processing by establishing agri-processing clusters in vulnerable districts, training local entrepreneurs and self-help groups on agri-processing techniques and proposal development under the National Horticulture Mission, creating growers' associations and tribal cooperatives for marketing, setting up grading and packing centers for fruits and processed products, and sensitizing agricultural cooperatives network on climate proofing production and marketing.
- Incentivize field and post-harvest technologies and develop a network of decentralized food processing zones especially in Vidarbha. Promote cultivation and proccessing of durum wheat variety in districts like Nanded and Latur. Similarly exotic vegetable clusters can be developed at Buldhana, Thane and Satara districts to augment income generation of the farmers.
- Capacity building and training of the local communities across the state especially youth regarding urban agriculture as an alternative source of livelihood. Training centers to be especially developed at Gondia, Gadchiroli, Usmanabad, Nanded, Latur, Nandurbar and Kolhapur.

Secure food supply chains

- Expand the cold storage infrastructure and continue to encourage farmers to use accredited warehouses by offering credit-linked interest subsidy on pledge loans taken by farmers on stored produce.
- Demarcate good agricultural land around large urban areas for development as food/ vegetable/ poultry zones in the city development plans, particularly in Mumbai, Pune, Nagpur, Nashik Aurangabad, etc. This will help reduce the growing city's carbon footprint and secure its food supply chain against climate risks.

4.2 Water resources

Impacts

- Increase in rainfall projected for future time periods. Rainfall follows an epochal trend. Increase in rainfall is projected in the 2030s, with a decline in rainfall by the 2050s. However rainfall in the 2050s is still likely to remain above the baseline.
- Projected increase in rainfall in the form of heavy precipitation events.
- Increase in surface run off is projected in certain catchments eg., sub-catchments of Godavari are expected to have increased runoff in the month of July

- Increase in the number of low rainfall days in south central Maharashtra indicates dry periods in this region which is likely to have an impact on water resources

Key recommendations

- Conservation and renaturalisation of rivers and water bodies
- Enhancement of water storage and groundwater recharge
- Improvement of water use efficiency

Action plan

- Retain and conserve the riparian zones and renaturalize existing wetlands in the state. Enhance native vegetation in these zones and formulate stringent policies to prevent the dumping of debris and waste in these zones.
- Modify the current tree policy to retain the mature trees, mainly around the origin of rivers which can help reduce soil erosion and downstream sedimentation. Hill areas where rivers originate can be declared as eco-sensitive zones and rewilded.
- Maintain the ecological flow in rivers both downstream and upstream of dams (20-30% of lean and non-lean period flows)
- Recharge underground aquifers through artificial recharge methods (such as percolation tank, recharge well, etc) in scientifically demarcated zones, by declaring green belt areas in urban areas, and by using paving materials that allow infiltration in urban areas.
- Prepare and implement action plan to augment water storage capacity in central Maharashtra to effectively harness the projected increase in rainfall for irrigation. Implement measures to conserve soil moisture for winter and summer crops, including improved planning and construction of watershed management structures like percolation tanks and check dams on rivers, tributaries, nalas, and downstream of dams based on sound technical assessment of aquifer conditions.
- Promote efficient use of irrigation water in districts with plantation crops, such as Aurangabad, Amrawati, Bhandara, Nagpur, Nasik and Jalgaon, through continued subsidies for drip and sprinkler irrigation systems and farm ponds, combined with extensive awareness campaigns for smaller and less educated farmers.
- Mandate water recycling and reuse by industries and utilities, and encourage early adoption through tax concessions. Also mandate regular water audits by industries and utilities and raise the prices for fresh surface water. As a supplementary measure to reduce the costs of compliance, provide incentives to domestic wastewater treatment equipment manufacturers.
- Make rainwater harvesting mandatory in new and existing structures in all million-plus population cities of Maharashtra. Facilitate compliance by making information about contractors and technologies available in a centralized database, undertaking a demonstration project in each ward, and providing property tax incentives.
- Mandate treatment and reuse of sewage water for gardening or flushing
- Augment stormwater drainage infrastructure in major cities of Maharashtra to accommodate a 15% increase in flood magnitude due to climate change.

4.3 Health

Impacts

- Increase in average number of days that are conducive to malaria transmission in some regions in eastern and coastal Maharashtra in the 2030s (e.g. Thane and Raigad) and 2050s (e.g. Gadchiroli)
- Faster rate of parasite development at higher temperatures even in regions with reduction in the average number of conducive days in the 2050s (e.g. Aurangabad, Jalna, Nashik)
- Increase in human discomfort due to heat stress in parts of Konkan, Nashik, and Nagpur divisions by the 2030s, as indicated by heat index that combines air temperature and relative humidity
- Increased risk of water borne diseases due to increases in mean rainfall and proportion of extremely high rainfall events. This requires adequate drainage and hygiene
- Reduced availability of fresh water due to saltwater intrusion into groundwater aquifers near the coast

Recommendations

- Enhance monitoring & community surveillance for climate-sensitive diseases and develop health-related climate services and early warning systems
- Invest in research related to climate change and health
- Improve overall health infrastructure and training

Action plan

- Develop early warning tools in collaboration with meteorological agencies for different end-users, e.g. early warning system for heat waves for urban centres such as Mumbai, for fishermen, for farming communities, and provide community climate services and health advisories.
- Develop and maintain a digital health database (e.g. cases reported daily, mortality, morbidity) at fine spatial and temporal scales for climate-sensitive diseases, including vector-borne diseases, water borne diseases, heat stress, and nutrition related disorders. Prioritize districts with a concentration of tribal populations such as Dhule, Nandurbar, Chandrapur, Gadchiroli, Bhandara, and Gondia.
- Promote community surveillance programmes and awareness programmes (e.g. for management of stagnant water). Expand community surveillance programme piloted under the Tribal Action Plan in Taloda and Akkalkuwa blocks of Nandurbar district to cover all other vulnerable districts.
- Study the regional pattern of climate-sensitive diseases and disease outbreaks (including malaria, dengue, chikungunya, diarrhea, and cholera) to identify changing trends and trigger events, and provide regular feedback to state surveillance units.
- Introduce norms for working hours for labourers to reduce their direct exposure to heat and construct shelters near farm areas, particularly in districts where temperature increase is projected to be high, such as in Nagpur division.
- Increase investment in health research on identification of linkages between temperature and rainfall increase and incidence of vector borne diseases, and on

mutations and emergence of new diseases due to changes in temperatures and humidity patterns.

- Introduce additional training module on climate change risks and impacts for health sector staff; to be imparted by the State Public Health Institute.

4.4 Ecosystems & livelihoods

Figure 8. Trends in land use and land cover change

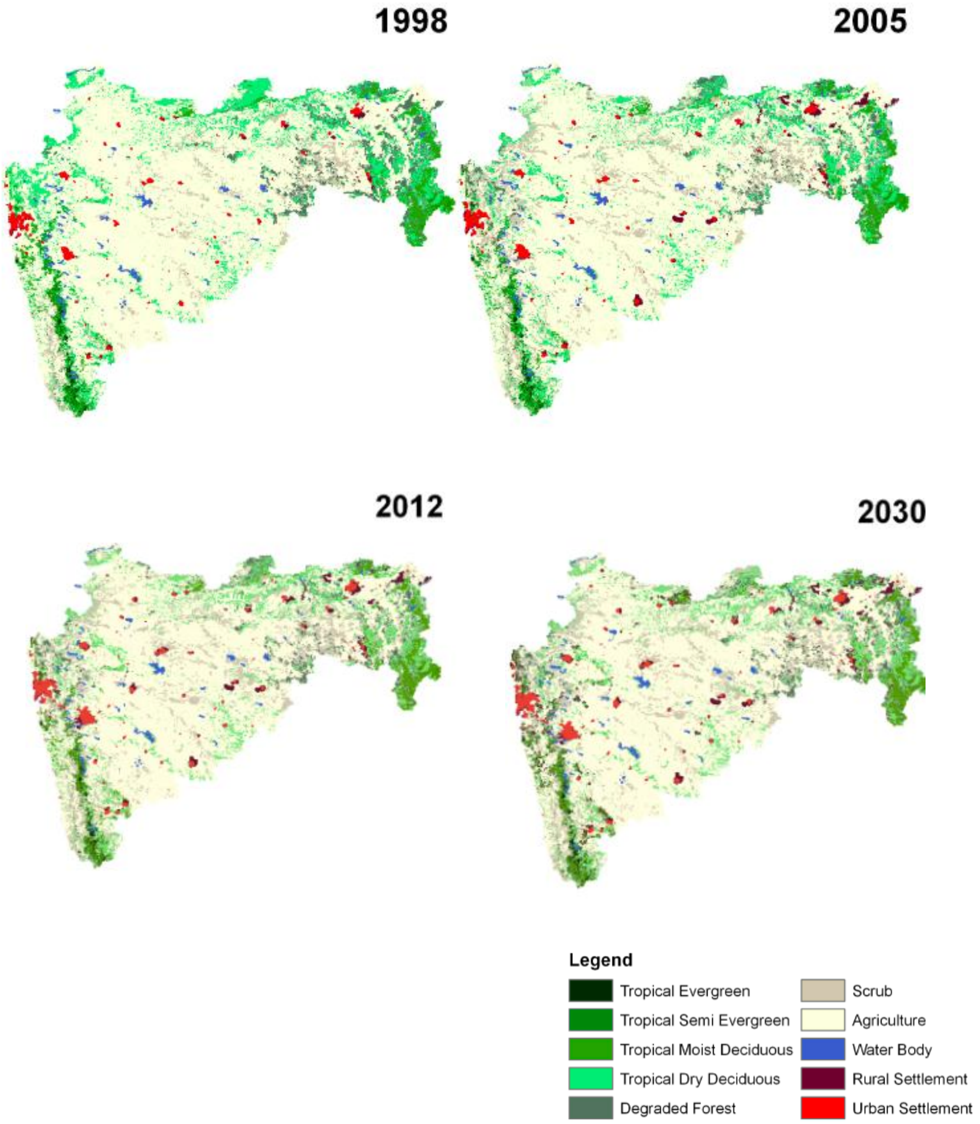
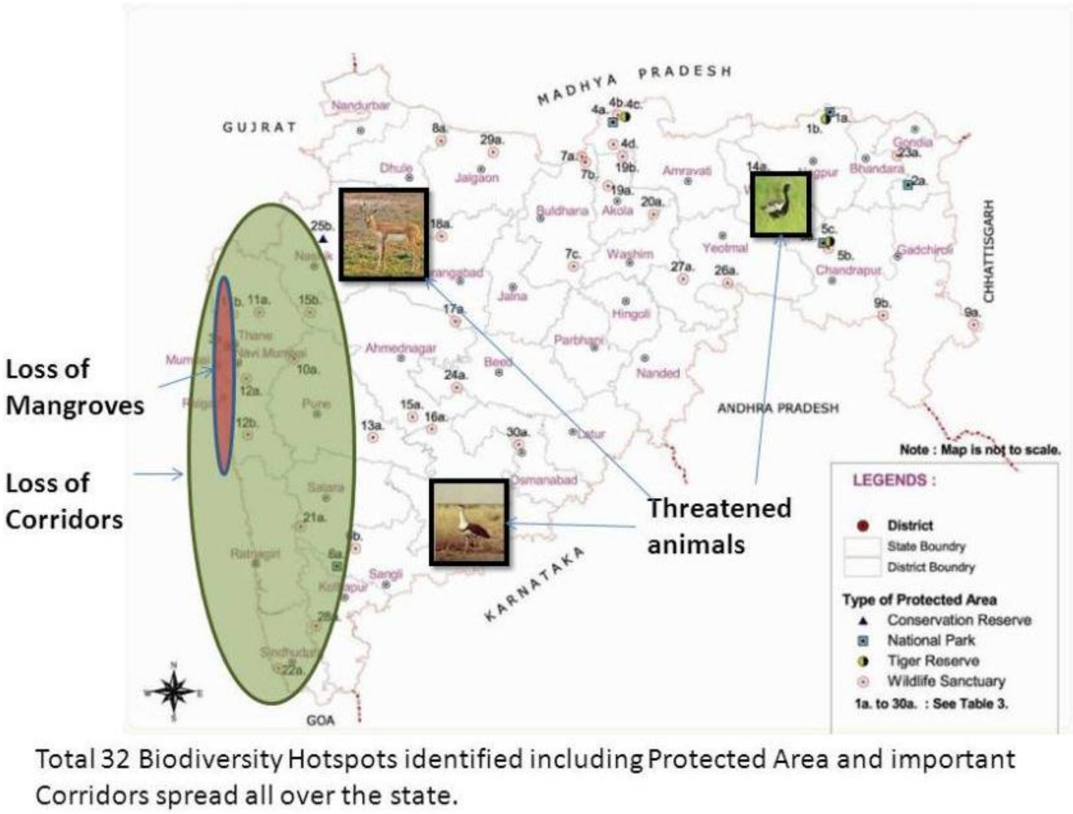


Figure 9. Region wise risks due to climate change



Impacts

Figure 8 shows the results of a predictive modelling assessment of changes in land use and land cover in Maharashtra. Tropical semi-evergreen forests, tropical moist deciduous forests and tropical dry deciduous forests have decreased over the period 1998-2012. If business-as-usual trends continue, there will be degradation of forests and fragmentation in the northern Western Ghats and loss of biodiversity corridors, which will make the region less resilient to the impacts of climate change. Figure 9 shows the risks presented by climate change for key species that are already vulnerable due to loss of habitat and other anthropogenic threats.

- Increased fire risk in savanna woodlands of Northern Western Ghats and Northern Vidarbha due to higher temperatures and arid conditions
- Increased aridity and reduced fodder supply in Marathwada, Khandesh, and Vidarbha.
- Local species loss especially of mangroves, fishes & associated biota due to increased salinity of water
- Longer term threats (by 2070s) to endangered species and ecosystems due to poor regeneration of species (Tropical evergreen forests of Western Ghats), habitat reduction for faunal species such as Chinkara, Maldhok (Bustard), Tanmore (Florican), etc. (Grasslands of Marathwada, Khandesh, Vidarbha).
- Longer term changes (by 2070s) in composition and quantum of fish landings and impacts on associated livelihoods

Recommendations

- Enhance quality of forest cover and improve ecosystem services

- Diversify livelihood options
- Promote scientific monitoring and research for improved decision-making

Action plan

Launch a Green Maharashtra Mission 2020 for biodiversity conservation

- Enhance quality of forest cover and improve ecosystem services in Western Ghats and Vidarbha through:
    - eco-restoration of degraded open forests in northern Western Ghats (north of Bhimashankar, Harishchandragad)
    - regeneration of NTFP species in Yavatmal, Buldhana and Gondia
    - restoration of grasslands in Washim and Akola
- Use ecosystem approach for restoration of over 21000 sq km of open forests in the state through:
    - rehabilitation of shifting cultivation areas in specific areas of Sahyadri and Vidarbha by developing alternative livelihood models
    - restoring scrublands, mangroves, and abandoned mining areas
- Enhance tree cover in cities with high growth in peri-urban areas like Pune
- Restore wetlands with a focus on tank based irrigation and fishery management system in Vidarbha
- Protect catchment areas of hydrological importance like that of Jaikwadi dam
- Develop biodiversity corridors by connecting remnant patches of forests in northern Sahyadri as well as creating new corridors
- Rejuvenate barren hillsides and degraded forests through corporate social responsibility (CSR) activities and the Ecological Wing of the Army, using carefully selected diverse native varieties.
- Encourage community participation in conservation through approaches such as Payment for Ecosystems Services e.g. compensating upstream communities for catchment protection.

Diversify livelihood options

- Develop agro-forestry and social forestry models based on mango and coconut in Konkan and bamboo in Vidarbha
- Provide local opportunities for value addition and income enhancement to communities with NTFP-based livelihoods
- Develop diversified livelihood options especially for fishery-dominated districts such as Sidhudurg and Ratnagiri.

Promote scientific monitoring and research for improved decision-making

- Institutionalize scientific research plans such as revival of existing forest monitoring plots in Bhimashankar, Mahabaleshwar, and protected areas.
- Generate information on temperature and precipitation thresholds for vulnerable ecosystems and associated species.

4.5 Energy & infrastructure

Impacts

- Given the projected increase in temperature, energy demand for cooling is likely to increase, particularly in urban areas like Thane, Pune, Aurangabad, and Nashik, which have a large population, growing development needs, and expanding residential and commercial spaces.

Recommendations

- Promotion of cleaner forms of energy
- Shift to energy efficient systems to conserve energy
- Climate proofing of new public infrastructure

Action plan

- Solar rooftop power generation in the urban areas which have large potential in commercial, industrial and residential buildings. Policy support at national and state level is required to reduce the cost of technology so as to facilitate effective implementation.
- Use of biomass based power generation, which will use biomass in efficient way and reduce the fossil fuel (diesel) consumption in DG sets.
- Introduction of policies for promoting usage of hybrid systems (solar and wind) in urban and rural areas. Institutions such as schools can benefit largely from such systems, since they can be independent of the electricity supply from the central grid.
- Use of renewable energy in agriculture processing applications such as cold storages (which are highly energy intensive and crucial for agricultural activities). Solar based small scale cold storage is one technology option that is commercially available as of now.
- Use of innovative applications like solar dryers and solar based pumping and irrigation for agriculture.
- Introduction of policies to encourage generation of renewable energy. One innovative measure is net metering which is a billing mechanism that allows residential or commercial customers who generate solar power to get credit for feeding surplus electricity back to the grid.
- Active promotion of waste-to-energy technologies as they have a dual benefit of power generation and easing the load on waste disposal system of the urban area.
- Climate proofing of new public infrastructure (like bridges, roads, ports, etc) by incorporating additional ranges of temperature, rainfall, and sea level rise into design specifications.

4.6 Cross-sectoral

- Integrate future climate change projections and uncertainties into state disaster management plans and disaster risk reduction strategies. For example, increased number of dry days is projected over south-central Maharashtra and increased intensity of rainfall is projected over northern Maharashtra in the 2030s relative to the baseline for these regions. Such changes from past climate need to be incorporated into the drought management and flood management plans.
- Incorporate climate change concerns into development plans and land use planning. For example if business as usual trends in land use and land cover change continue,

there could be increased fragmentation and degradation of forests, making these ecosystems more vulnerable to climate change, as well as the dependent species and livelihoods. Land use zoning and development planning can be oriented to protection and restore such ecosystems aand make them more resilient to climate change.

5. Sector-specific departmental responsibilities

A summary of sector-specific adaptation recommendations and concerned departments is given in Table 3.

Table 3. Sector-specific adaptation recommendations and concerned departments

Sector	Vulnerable regions	Sector and key adaptation recommendations	Concerned departments
Agriculture	Nashik, Dhule, Ahmednagar, Aurangabad, Gadchiroli and Wardha	• Safeguard farmers against climate risks through improved access to climate services, risk management strategies, and safety nets against climate extremes • Enhance resilience of farming systems through diversified cropping patterns, soil conservation, and value addition • Secure food supply chains	Agriculture Department Irrigation, Water Resources, and Forest Departments India Meteorological Department State agriculture universities and KVKs
Water resources	Origins and catchment areas of river basins	• Conservation and renaturalisation of rivers and water bodies • Enhancement of water storage and groundwater recharge • Improvement of water use efficiency	Urban Development Department Environment Department Water Resources Department Rural Development Department
Health	Coastal Maharashtra and eastern parts of the state	• Enhance monitoring & surveillance for different climate-sensitive diseases and develop health-related climate services and early warning system • Invest in research related to climate change and health • Improve overall health infrastructure and training • Promote community surveillance programmes and awareness programmes	Health Department
Ecosystems	Northern Western Ghats, and Marathwada,	• Enhance quality of forest cover and improve	Forest Department

	Khandesh and Vidarbha grasslands	ecosystem services • Diversify livelihood options • Promote scientific monitoring and research for improved decision-making	
Energy & Infrastructure	Thane, Pune, Aurangabad, Nashik, and other cities	• Promotion of renewable energy and waste to energy • Climate proofing of new public infrastructure	Maharashtra Energy Development Agency Urban Development Department
Cross-sectoral		• Integrate future climate change projections and uncertainties into state disaster management plans and disaster risk reduction strategies. • Incorporate climate change concerns into development plans and land use planning	State Planning Commission

Appendix 1. District-wise climate change projections

District	Projected increase in monsoon rainfall (% increase from baseline)					
	2030s		2050s		2070s	
	Avg	Range	Avg	Range	Avg	Range
Hingoli	22.9	17.5-27.5	26.3	22.5-30	28.16	25-32.5
Buldana	26.23	22.5-30	28.74	25-32.5	21.88	17.5-30
Thane	25.16	20-30	24.71	20-30	27.32	20-32.5
Gondia	17.46	15-20	18.76	15-20	25.06	22.5-27.5
Nandurbar	33.83	27.5-37.5	31.43	27.5-37.5	21.01	15-30
Solapur	15.39	10-20	15.41	10-20	25.03	17.5-32.5
Sindhudurg	12.81	7.5-15	10.98	7.5-15	15.4	10-25
Kolhapur	15.30	10-20	15.05	7.5-20	22.7	15-30
Ratnagiri	15.42	7.5-20	15.26	7.5-20	18.7	10-27.5
Sangli	12.97	12.5-20	12.04	10-22.5	23.6	17.5-32.5
Solapur	14.25	10-17.5	13.77	7.5-20	22.8	17.5-30
Satara	17.90	12.5-22.5	16.25	12.5-22.5	26.1	22.5-35
Raigad	20.10	17.5-25	19.62	15-22.5	20	17.5-25
Pune	25.76	10-32.5	25.03	10-30	28.7	20-37.5
Osmanabad	19.80	12.5-25	20.16	12.5-27.5	29.9	22.5-37.5
Latur	17.93	15-22.5	21.6	15-25	32.8	27.5-35
Nanded	19.22	12.5-25	23.3	17.5-30	28.4	17.5-30
Beed	22.65	20-30	26.2	17.5-30	34	30-40
Ahmednagar	22.93	15-32.5	23.85	15-35	35.15	30-40
Nashik	34.78	25-40	32.92	22.5-40	38.6	30-52.5
Aurangabad	24.95	20-27.5	25.05	20.5-27.5	27.3	20-32.5
Jalna	23.40	20-25	24.1	22.5-27.5	26.98	20-32.5
Parbhani	22.64	15-25	23.5	20-27.5	30.1	27.5-32.5
Dhule	36.70	30-40	33.4	27.5-37.5	24.7	17.5-30
Jalgaon	35.29	25-40	34.9	25-37.5	22.6	17.5-27.5
Yavatmal	22.35	17.5-27.5	26.8	22.5-32.5	20.15	15-27.5
Chandrapur	16.2	12.5-22.5	21.7	17.5-30	17.9	15-25
Gadchiroli	18.15	12.5-22.5	23.4	12.5-30	22.06	20-30
Washim	23.2	22.5-27.5	28.7	25-30	22.7	20-27.5
Akola	26.2	22.5-30	30	27.5-32.5	20.6	20-25
Amravati	21.7	17.5-27.5	26.2	22.5-30	22.4	17.5-25
Wardha	18.1	15-22.5	20.9	20-27.5	18.75	15-25
Nagpur	17.5	15-20	21.89	17.5-22.5	25.1	17.5-27.5
Gadchiroli	20	12.5-22.5	21.4	12.5-30	22.85	20-30
Bhandara	17.6	15-20	20.7	17.5-22.5	22.8	22.5-27.5

Note: The climate model used for this study is designed to model the climate over Maharashtra state and is not specifically designed for district-scale climate projections. The resolution of the model is 25 km x 25 km.

1. Introduction

Global and national concern related to future climate change

Scientific evidence at the global level has unambiguously established that over the past 150 years our Earth has warmed by 0.74°C (range: 0.56 to 0.92°C) and climate models project a further rise in global mean temperature by the end of this century in the range of 0.6 to 4.0°C over 1980-99 levels (IPCC 2007). The 2007 Fourth Assessment Report (AR4) of the Inter-governmental Panel on Climate Change[9](IPCC) attributes most of the increase in observed global average temperatures since the mid-20th century to be *very likely* linked to the observed increase in anthropogenic greenhouse gas concentrations over the same period. As per the United Nations Framework Convention on Climate Change (UNFCCC), Article 1, climate change could be defined as *a change of climate which is attributed directly or indirectly to human activity, that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period*. There is now international consensus on the urgency of the need to undertake meaningful measures towards the containment of all such high-emission activities. The aim is to limit the increase in global mean temperature to the 'guardrail' of 2°C through international collective action on emissions reduction. However, the UNFCCC-based regime is yet to see a successful outcome of the negotiations happening amongst countries to identify and adopt equitable burden-sharing mechanisms consistent with the principle of 'common but differentiated responsibility'.

While effective international action on GHG mitigation is awaited, there is a growing inevitability to climate change and its consequent impacts. The IPCC AR4 (2007) predicts an increase in the magnitude and frequency of extreme events including droughts, floods and cyclones and increased sea level. The IPCC Special Report on Extreme Events (2012) summarizes the results of many climate models to show that extreme hot days (which normally occur once in 20 years) will occur more frequently (once in 2-4 years) in South Asia by the middle of this century; heavy rainfall days (which normally occur once in 20 years) may also occur more frequently (once in 10-12 years). Several national, regional and local case studies indicate that fluctuations in climatic patterns have already affected physical and biological systems to varying degrees and further threaten to have effects that would only increase in case of inaction. India's initial National Communication (NATCOM) (GoI, 2004) to the UNFCCC highlights some of the major threats that India faces in the context of climate change, which include:

- Reduction in the availability of fresh water
- Impacts on agriculture and food security due to predicted decline in rainfall
- Boundary shifts for different forest types, withconsequent implications for species diversity and forest-dependent communities
- Adverse impacts on natural ecosystems such as wetlands, mangroves and coral reefs and mountain ecosystems
- Threat of sea-level rise along coastal zones

[9]IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp

- Changes in virulence and disease patterns especially vector borne diseases due to prevalence of conducive environments and,
- Increased energy demands and subsequent impacts on climate-sensitive infrastructure

Climate change, though global in nature, has impacts that are also felt at regional and local scales. Vulnerability to climate change arises not only because of exposure to climatic hazards, but also the sensitivity of resource systems and a society's coping capacity. The State of Maharashtra with a long coastline, varied geography, large poor population, and an economy closely tied to climate sensitive sectors like agriculture is likely to be highly vulnerable to impacts of changes in temperature, precipitation patterns, frequency and intensity of extreme events such as droughts, floods, cyclones, heat waves etc. In this context, assessing current and future vulnerabilities, climate change impacts, and adaptation needs is of vital importance to the State's policy making and planning process.

India's National Action Plan on Climate Change (NAPCC)

In 2008, India's Prime Minister Dr. Manmohan Singh released the country's National Action Plan on Climate Change (NAPCC). The Action Plan which has been prepared under the guidance of Prime Minister's Council on Climate Change identifies strategies to promote India's development objectives as well as to achieve co-benefits for addressing climate change related issues of adaptation and mitigation. The plan outlines a set of existing and future policies as well as programs for achieving sustainable development path that also meets the economic and environmental objectives of the country. The plan emphasizes equity as one of its key underlying principles and mentions that each individual on this planet should have an equal share of the atmospheric space. It pledges that India's per capita greenhouse gas emissions will at no point exceed that of developed countries even as we pursue our development objectives.

The NAPCC accentuates that our overriding priority is maintaining high economic growth rates to raise living standards of the people and reduce their vulnerability to the impacts of climate change. Some of the guiding principles of the plan include 'protecting the poor and vulnerable through an inclusive and sustainable development strategy sensitive to climate change' and 'deploying appropriate technologies for both adaptation and mitigation of greenhouse gases emissions'. 'Effecting implementation of programmes through unique linkages, including with civil society and local government institutions and through public-private-partnership' is also one of the guiding principles of the NAPCC.

Under the NAPCC, eight National Missions have been identified which form the core of this plan. These Missions structure out a detailed plan of long term and integrated strategies to achieve the overall objectives of the NAPCC with respect to climate change adaptation and mitigation. These missions include the National Solar Mission, National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for a Green India, National Mission for Sustaining the Himalayan Ecosystem, National Mission for Sustainable Agriculture, and National Mission on Strategic Knowledge for Climate Change. Institutionalized by the respective ministries, these Missions detail out the measures to align the existing programmes to address climate change issues as well as devise new strategies.

One of the key thrust areas to be addressed under the National Mission for Sustainable Agriculture (NMSA) includes dryland agriculture. The NAPCC also mentions one of its objectives as to devise strategies to make Indian agriculture more resilient to climate change by focusing on improving the productivity of rainfed agriculture. This specifically finds relevance in the context of the State of Maharashtra where about 84% of the gross cropped area is rainfed and more than 30% of the state falls under the rain shadow area (Economic Survey of Maharshtra 2011-12). About 60% of the total geographical area of the State is under agriculture (net sown area) and a large population is directly dependent on agriculture for their livelihoods. In 2012, many parts of the State faced drought conditions which not only affected the crop productivity but also had an impact on the livelihoods of the people. Devising specific strategies for Maharashtra as part of the NMSA's focus area which is to realize the enormous potential of growth in dryland agriculture through development of drought and pest resistant crop varieties, adopting resource conserving technologies, providing institutional support to farmers and capacity building of stakeholders can potentially contribute in making the agriculture dependent communities in the State more resilient to climate variability. Promoting "laboratory to land" research by creating Model Villages and Model Farm Units in rainfed and dryland areas is also one of the focus areas under the NMSA which can also assist in enhancing the adaptive capacity of the people in Maharashtra. Apart from dryland farming, measures to enhance agricultural productivity through customized interventions such as use of bio-technology to develop improved varieties of crops and livestock, promoting efficient irrigation systems, demonstration of appropriate technology, capacity building and skill development under the NMSA can help in making agriculture more sustainable in the State.

As agriculture in Maharashtra is largely rainfed thus, conservation of water becomes mandatory to ensure good crop productivity. One of the key goals under the National Water Mission (NWM) includes promotion of citizen and state action for water conservation, augmentation and preservation. This finds relevance for the State as the strategies identified under this goal such as empowerment and involvement of Panchayati Raj Institutions, urban local bodies, Water Users' Associations and primary stake holders in management of water resources with focus on water conservation, augmentation and preservation can greatly contribute in ensuring better water availability in many of the drylands. The NWM mentions one of such success stories of Hiware Bazar village in Ahmednagar district in Maharashtra where an integrated model of development with water conservation as its core has been adopted. The village faced acute water shortage earlier but with the help of community efforts, watershed structures were constructed and plantation and forest regeneration activities were undertaken which resulted in increase of groundwater level in the region giving many other benefits for agriculture and livelihoods.

Increasing water use efficiency by 20% is also one of the other goals under the NWM and includes strategies such as use of micro-irrigation techniques. The Maharashtra government has been encouraging the use of drip and sprinkler irrigation in the State by providing subsidies as the use of these techniques can help in addressing many issues related to water availability, especially in the drylands of Marathwada region.

Need for the Maharashtra State Adaptation Action Plan on Climate Change (MSAAPCC)

Subsequent to the framing of the NAPCC, the Government of India in August 2009 directed the States to develop individual State Action Plans on Climate Change guided by and consistent with the structure and strategies of the NAPCC. The individual SAPCCs are expected to lay out sector- specific as well as cross sector time-bound priority actions, along with indicative budgetary requirements, supplemented with details of the necessary institutional and policy infrastructure to support the operationalization of actions. In order to decentralize NAPCC objectives into local context, a common framework has been developed (MoEF, 2010) which emphasizes on harmonizing national and state level actions while also incorporating regional and site specific variations. The common framework is expected to enable proper coordination of the process of preparation of SAPCCs and its subsequent implementation under varied regional and local contexts.

The Government of Maharashtra took a pioneering step towards formulating the Maharashtra State Adaptation Action Plan on Climate Change by commissioning a comprehensive vulnerability assessment study which included the task of generating model-based climate projections specific to the State's geography. The relevance of such a study is well established in the context of adaptation which by its very nature is localized in action.

State action on climate change is also justified under the Indian Constitution which distributes responsibilities and demarcates the areas of jurisdiction amongst the different levels in our country's federal system of governance. The distinction of responsibilities as elaborated in the Union List and the State List is an important foundation to define the scope of State-level climate policy in India. Some of the sectors directly related to natural resources, such as agriculture, water, fisheries, mines and land use, are placed under the jurisdiction of individual States. In addition, sectors such as selected industries and transport, which are important concerns of climate policy-makers by virtue of being energy- and emissions- intensive in nature, are also the components of the State List. On the other hand, several areas relevant to climate policy, including trade representation, agreements and conventions, atomic power, mineral and oil resources are concerns of the Union. This division of responsibilities highlights the magnitude of influence States potentially exert on climate policy and environmental decision making in general.

States also have an important responsibility of implementing the policies formulated at the national level. This provides significant opportunities for SAPCCs to introduce technological and regulatory innovation. Finally, decentralized decision-making that goes into the formulation of SAPCCs is expected to be more efficient compared to a uniform nation-wide approach that is indifferent to local factors and ground realities.

Developing the MSAAPCC: vision, guiding principles, the process, and partnerships

1.4.1 Vision

Recognizing the wide range of projections of climate change, noting the linkages between development and climate change adaptation, and appreciating the development goals of its population, the Maharashtra State Action Plan on Climate Change (MSAPCC) aims to increase the resilience of the people and the economy of Maharashtra to future climate change. This requires identifying those who are most vulnerable to the potential adverse impacts of climate change. It requires understanding the limits to how people cope and to help them adapt.

1.4.2 Approach and Guiding Principles

The approach to developing the Maharashtra State Adaptation Action Plan on Climate Change (MSAAPCC) has been driven by the above-stated Vision, which emphasizes the core concerns of the State Government related to the *uncertainty* surrounding future climate risks at the local level, the challenge of building long-term *resilience* in the development process and overcoming the constraints of *capacity*.

The Government of India's Ministry of Environment and Forests (MoEF) has developed a set of guiding principles for preparation of the SAPCCs, which has been taken into consideration in preparing the MSAAPCC (Table 1).

Table 1: Guiding principles for preparation of the SAPCC (MoEF 2010)
▪ Implementing inclusive and sustainable development strategy that protects the poor and vulnerable sections of society from adverse effects of climate change
▪ Undertaking actions that deliver benefits for growth and development while mitigating climate change
▪ Ensuring and improving ecological sustainability
▪ Building climate scenarios and investing in knowledge and research to reduce uncertainty and improve knowledge about appropriate responses
▪ Assessing impact of climate change on existing vulnerabilities, and Identifying and enhancing risk management tools for addressing climate change
▪ Setting out options and evaluating and ranking them according to criteria (cost-effectiveness, cost-benefit, feasibility, ease of implementation, "no-regrets", robust to different scenarios, incremental vs transformative change etc)
▪ Identifying and implementing state-planned and community-based voluntary/autonomous adaptation
▪ Building broader stakeholder engagement to maximize perspectives and involvement in implementation
▪ Addressing state-specific priority issues, whilst also creating appropriate enabling environment for implementation of NAPCC at state level
▪ Considering governance and institutional contexts and ensuring appropriate Institutional arrangements and building capacities, keeping in view the coordination, inter-departmental consultations, stakeholder involvement, and integration with regular planning and budgetary processes
▪ Estimating additional resource requirements and exploring existing and new & additional carbon

Table 1: Guiding principles for preparation of the SAPCC (MoEF 2010)
finance potential
▪ Linking up with national policies and programmes for consistency and to identify financial or policy support that may be available

The approach adopted in the preparation of the MSAAPCC is defined by investment in research to generate scientific knowledge that can be used for policy formulation, priority consideration to the State-specific development issues, wide-ranging stakeholder engagement, and the focus on capacity creation within the government. While seeking to ensure that the identified adaptation actions are coherent with national priorities, the foremost emphasis has been on identifying ways and means to *mainstream* climate action in the State's own development plans as reflected in the ongoing programmes and schemes. Most importantly, the approach provides scope for taking account of varying socio-economic circumstances within Maharashtra and seeks to formulate locally relevant adaptation actions that would address the sources of vulnerability specific to the region and its people.

It is important to emphasize the key aspect of *uncertainty* that is inherent to current knowledge and understanding of the nature of risks that are likely to emerge in the future on account of climate change and the scale of their consequences. The state-of-the-art modeling tools and impacts assessment methods have their own limitations in addressing this uncertainty and it is undoubtedly challenging – in terms of availability of scientific expertise and resources – to generate the requisite strategic knowledge so essential for informed decision-making on adaptation to climate change. Hence, the SAPCC needs to be a *dynamic* document that should follow a regular interactive and iterative process to reflect new knowledge and developments at the national, state and local levels.

1.4.3 Process of developing the MSAAPCC

1.4.3.1 TERI – UKMO Study on "Assessing Climate Change Vulnerability and Adaptation Strategies for Maharashtra State"

The Department of Environment, Government of Maharashtra initiated the process of creating the MSAAPCC by commissioning an ambitious vulnerability assessment study for the State in April 2010. The study – carried out by TERI in partnership with the UK Met Office –broadly aimed to "address the urgent need to integrate climate change concerns into the State's overall development strategy, thus assisting in building long term climate resilience and enabling adaptation to the likelihood of risks arising from climate change".

The core task undertaken in the study was to assess the regional impacts of climate change in the State, using climate projections for the 2030s, 2050s and 2070s generated from a state-of-the-art climate modeling exercise carried out by the UK Met Office. The four priority sectors chosen by the Government of Maharashtra for impacts assessment are (a) Hydrology & fresh water resources (surface and ground); (b) Agriculture & food systems (livestock, dairy, fishery, etc); (c) Coastal areas marine ecosystem and biodiversity; and (d) Livelihood (including migration and conflict). Additionally, the study has covered issues related to human health, ecosystem and biodiversity, forests, markets, and risk management. Based on the sector and cross-sector impacts assessments, and taking account of the regional diversity within the State, the study was expected to identify implementable adaptation measures along with the associated capacity needs.

The vulnerability assessment study has played a key role in the finalization of the MSAAPCC because of the strategic knowledge that it has generated for the State. While the box alongside gives the chronology of the study, Figure 1 below presents a schematic outline of the key steps followed in the study.

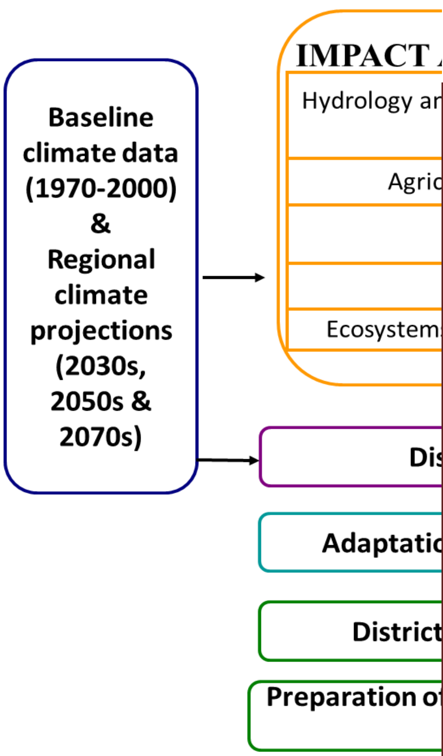


Figure 1: Key steps involved in the State Vulnerability Assessment Study for Maharashtra

19 June 2009: Dr. R. K. Pachauri met the Hon'ble Chief Minister, Deputy CM, Cabinet Ministers, Chief Secretary, Senior officials in Maharashtra to conceptualize the study

31st March 2010: Project officially launched with signing of MoU between Govt. of Maharashtra and TERI. The project website was unveiled.

10 June 2010: Project Launch and Awareness Workshop

10 January 2011: Review Meeting with Secretary, Environment

3 June 2011: Review Meeting with Joint Secretary, MoEF and Secretary, Environment

13 September 2011: Review Meeting with Hon'ble Chief Secretary and Secretary, Environment

25 January 2012: Review meeting with Hon'ble Chief Secretary

7th August 2012: Presentation before Hon'ble Cabinet Minister for Environment and State Environment Minister

2 January 2013: Meeting with State Environment Minister

14 February 2013: Presentation before the State Council on Climate Change

7 October 2013: Presentation before the Chief Secretary and State Departments of Maharashtra

1.4.3.2 Stakeholder consultations

In preparing the MSAAPCC there was a constant focus on stakeholder engagement through formal as well as informal consultations. As part of the vulnerability assessment study several workshops and meetings with key government officials – including district administration and line agencies – have been conducted. The study's website solicited views and suggestions on issues pertinent to the State in the context of climate change. Several major workshops provided opportunity to representatives of various stakeholder groups for sharing their expert understanding as well as insights gained from experience. Table 4.2 presents an illustrative list of major events-based consultations that have contributed to the MSAAPCC.

Table 4.2: Events and consultations related to the preparation of the MSAAPCC	
Presentations to Government of Maharashtra, Mumbai, October 2013 and July 2013	▪ Presentation to Chief Secretary and Principal Secretaries of various departments and suggestions to finalize study ▪ Presentation to Environment Secretary and suggestions for additional analysis
Meeting of the State Council on Climate Change, Mumbai, February 2013	▪ Participation by the Chief Minister, Cabinet and State Minister for Environment, Principal Secretaries and Secretaries, Members of the State Council ▪ Suggestions about points to be included in the study conducted by TERI ▪ Suggestions on issues pertaining to climate change that need priority attention by the State government
State level Brainstorming Session on "Development of Urban Wetlands of Maharashtra: Needs, Gaps and Way Forward", Mumbai, February 2013	▪ Participation by Chief Secretary, Principal Secretaries - Urban Development and Forest, Secretary – Environment, City and Industrial Development Corporation of Maharashtra, Municipal Commissioners, Town Planners, Urban Planners, NGOs ▪ Action points identified include (i) developing a policy paper focusing on urban wetlands; (ii) suitably amending policies and by-laws and regulating development around wetlands; (iii) identifying sites for dumping of construction debris in urban areas on priority basis and strictly protecting wetlands from dumping of urban waste including debris; (iv) better dissemination of information about available resources including both financial and technical, so as to facilitate conservation of wetlands; (v) building capacity through imparting training to city engineers and town planners highlighting the significance of wetlands and technological interventions for wetland restoration
Conference on "Climate Variability and Cash Crops of Maharashtra", Thane, January 2013	▪ Participation by government officials, representatives of NABARD, IMD, Corporates, NGOs, Farmer Clubs, SHGs ▪ Enhanced awareness pertaining to risks and vulnerabilities associated with climate variability in the state of Maharashtra especially in the context of the cash crops; Opportunities associated with exploring technology like food processing, information communication technology and so on; Integrating the agro advisory services and weather forecasts in to the agricultural calendars of the farming communities; Significance of crop diversification; Striking the right balance between the

Table 4.2: Events and consultations related to the preparation of the MSAAPCC	
	traditional as well as the modern practices ▪ Addressed issues pertaining to crop failures and plausible solutions, delayed monsoons and increasing temperatures and their consequent impacts, shift towards resource intensive crops and their long term sustenance in the purview of climate vagaries ▪ Success stories and case studies
District Workshops and Consultations on Local Adaptation Programme in Hingoli, Nandurbar, Gondia, Buldhana, Thane, Sholapur, October – December 2012	▪ Participation by officials from government agencies at both district and block levels, Village Heads, Farmers Groups including women, Local NGOs ▪ Focus on assessing adaptation needs and identifying locally-relevant adaptation strategies
Conference on "Climate Change and Sustainable Agriculture", Mumbai, April 2011	▪ Participation by government officials, scientists, representatives of NGOs and Farmers' Cooperatives, corporate representatives, NABARD, teachers, etc ▪ Focus on specific case studies of climatic risks to crops like onion, grapes and pomegranate; role of technology and financing opportunities
Workshop on Climate Change, Mumbai, February 2011	▪ Participation by government officials, researchers, NGO representatives, media ▪ Focus on sensitization and capacity building among government officials
Project Launch and Awareness Workshop on 'Assessing Climate Change Vulnerabilities and Adaptation strategies' for the State of Maharashtra, Mumbai, June 2010	▪ Participation by the Chief Secretary and other senior government officials ▪ Discussions on the need for preparedness within the State to adapt to climate change impacts and enhancing capacity for developing and implementing appropriate adaptation strategies ▪ Focus on key leverage points and research needs for mainstreaming climate change into development planning

1.4.3.3 State Council on Climate Change

The process of preparing the MSAAPCC has culminated in the setting up of the State Council on Climate Change in July 2011 to guide the preparation of the State Action Plan on Climate Change and ensure coordinated efforts on all climate change related issues. The Council is chaired by the Chief Minister, with the Deputy Chief Minister acting as Co-Chairman. The members of the Council include the Ministers for Environment, Agriculture, Water Resources, and Rural Development, along with the Chief Secretary. The Council also has experts from research institutions, scientific institutions, corporate sector, and non-governmental organizations.

Distinguishing features of the MSAAPCC

The MSAAPCC is distinguished by its use of custom-generated data on future climate scenarios and its integration with socio-economic and land use and land cover change projections. The identification of specific adaptation actions has been guided by a comprehensive vulnerability assessment exercise for the State, which is unique in the context of State Action Plan preparation in the country. The identification of vulnerability 'hotspots' and the consequent consultative process to generate and prioritize actions that constitute a Local Adaptation Programme of Action (LAPA) has ensured that this policy formulation exercise has gone beyond the conventional uni-directional 'top down' process.

There is considerable regional variation within Maharashtra, both in terms of economic development and natural resources availability. The MSAAPCC has tried to account for this variation in the identification of the strategies. By focusing on phenomena such as induced migration and conflicts, the need for paradigm change in policymaking has been established. The adaptation framework adopted by the MSAAPCC gives core consideration to the water-energy nexus, which is increasingly becoming a paramount concern in the drought-hit State.

State preparedness to act on climate change is often severely constrained because of a lack of adequate sensitization and decision-making capacity within the government. This aspect is typically not given the emphasis it warrants. The MSAAPCC, while seeking to promote awareness and capacity in society and among key stakeholders, has a specific focus on assessing capacity needs within the government and acting on it. The proposed Climate Change Cell in the government is expected to carry out this mandate in partnership with reputed knowledge organization within and outside the State.

'Mainstreaming' climate action in the State's development planning is the mantra of this policy document and all efforts have been made to identify the linkages between the proposed adaptation actions and the ongoing policies and programmes in the State. At the same time, given the focus of the MSAAPCC's Vision to create long term resilience in society and natural resource systems, the emphasis has been on identifying new and additional actions in the key domains of strategic knowledge, ecology and infrastructure, social protection, and institutions.

The MSAAPCC is a rare illustration of the top political leadership in the State getting directly engaged in providing the vision and direction. The institutionalization of this engagement by the establishment of the State Council on Climate Change would ensure that the implementation of the Action Plan is effectively guided and monitored.

2. Socio-economic, ecological and climate profile of Maharashtra

2.1 Geography

Maharashtra is the third largest State in India accounting for 9.4% (3,07,731km^2) of the total geographical area of the country and the second most populous State with a population of about 112 million (2011 Census). Based on socio-political and other geographical considerations, the State is divided into five main regions: Vidarbha (north-eastern region), Marathwada (south-central region), Khandesh (north-western region), Northern Maharashtra and Western Maharashtra (Konkan). Maharashtra occupies the western and central part of the country and has a long coastline stretching nearly 720 km along the Arabian Sea. The Western Ghats is not only the prominent biodiversity resource for the region and an important climatic divide (average elevation of 1200 metres), but also forms one of the three watersheds of the State from which originate several important rivers, including Godavari and Krishna.

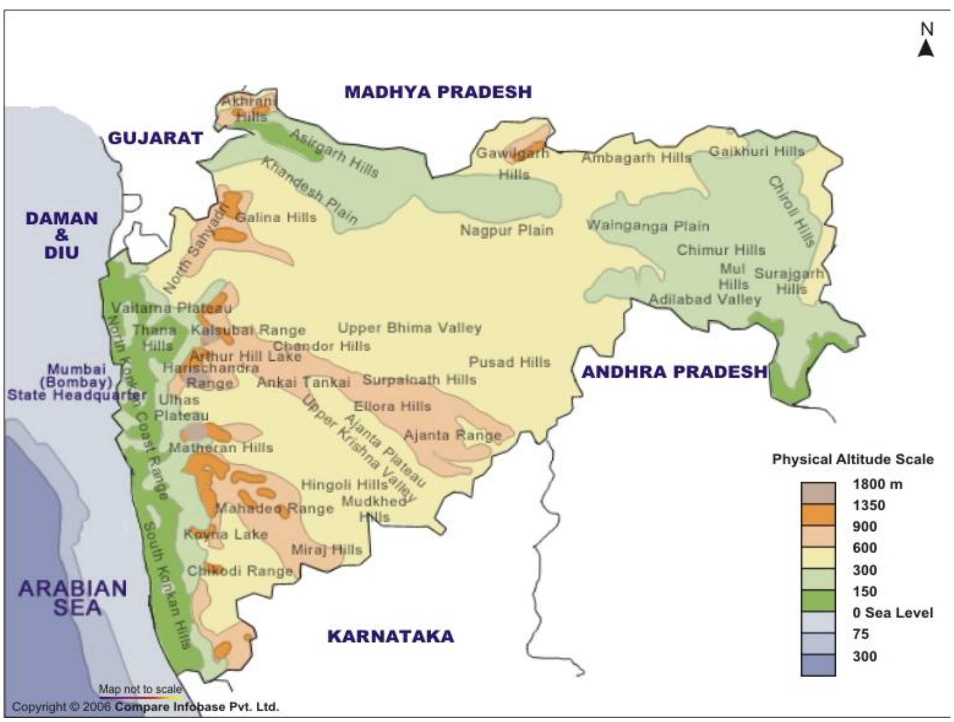


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Figure 1: Physical map of Maharashtra (Source: www.mapsofindia.com/maps/maharashtra)

2.2 Socio-economic conditions

Going by the 2001 census figures, 57% of the total population in Maharashtra belongs to the rural category. Population trends for the period 1991-2011 reveal a steady decadal increase but at a decreasing rate – the annual growth rate during 2001-11 is 1.6% compared to that of 2.3% during 1991-01 as per the 2011 census estimates. The population density shows an increase from 315 persons/km^2 in 2001 to 365 persons/km^2 in 2011; the corresponding national average is 382 persons/km^2. However, Mumbai (Suburban) and Mumbai districts have population density in excess of 20,000 persons/km^2, whereas in three districts – Thane (1175), Pune (603) and Kolhapur (504) – the density is more than 500. On the other hand, four districts – Gadchiroli (74), Sindhudurg (163), Chandrapur (192) and Ratnagiri (196) – have population density less than the State average. The State registered one of the largest in-migration figures of the country with an addition of around 4 lakh people every year during 1991-2001 (SRS, GOI).

According to the Planning Commission of India, Maharashtra has 30.7% population living below the poverty line[10] as on 2005. The State ranks 6th in terms of social and economic infrastructure, which is higher than the country average. Among the Indian states, it ranks 4th in terms of the HDI, which takes into account factors of literacy (77%), life expectancy at birth (65.5 years), infant mortality rate (48 per 1000 births) and maternal mortality rate (13.5 per million births) (HDR, 2003)[3]. According to the 2011 census, literacy rate for the State stands at 83% - although there is wide disparity by gender (male-90; female-75) - which is above the national average of 74%.

Agriculture is the primary source of livelihood in the State with nearly 60% of the working population engaged directly in farming activities (HDR, 2003). Though the proportion of area under agriculture in the State is 57.2%, which is more than the national average of 43.4%, the share of agriculture and animal husbandry in the GSDP has remained comparatively low at 13%. More than 30% of the area of the State falls under rain-shadow region where scanty and erratic rains occur and about 84% of the total area under agriculture is directly dependent on the monsoon. The proportion of irrigated area in the State is only around 16%, as opposed to the national average of 38%. Also, land holdings are small, with 40% of landholdings in less than one-hectare 'marginal' category. Consequently, the per hectare crop yield is lower than the national level. There have been drastic changes in the land use patterns – primarily reduction in forest and agriculture land and at the same time increase in built-up area.

10 Planning commission Poverty estimates for India (2004) available at http://www.planningcommission.gov.in/news/prmar07.pdf last accessed on 29-03-10

2.3 Climate

A wide variation in the distribution of rainfall is seen across the State, with the coastal belt, the Konkan region, receiving more than 2,000 millimeters annually, and the second highest rainfall being recorded in the Vidarbha region. Rainfall in Maharashtra increases steadily towards the east and average rainfall in the easternmost districts is about 1,400 millimeters. The rain shadow and Marathwada regions are the drought-prone areas of the State, with an annual average rainfall of less than 600 millimeters. These regions are generally characterized by extreme aridity, hot climate, and acute deficiency in water availability. More recently, areas in Vidarbha, which usually have reliable rainfall, have experienced variable and reduced.

A warming trend has been established over Maharashtra for both maximum and minimum temperatures over the past 100 years. Although uniform maximum temperatures between 34^{0}C to 40^{0}C are seen over large parts of India, steep temperature gradient during pre-monsoon season is found over the west coast including parts of Maharashtra. The seasonal temperature variation is considerably modified by the southwest monsoon. The spatial changes in minimum temperatures are observed to be decreasing in most parts of Western Ghats. Pre-monsoon maximum temperatures have increased significantly over the west coast (Kothawale and Kumar, 2005).

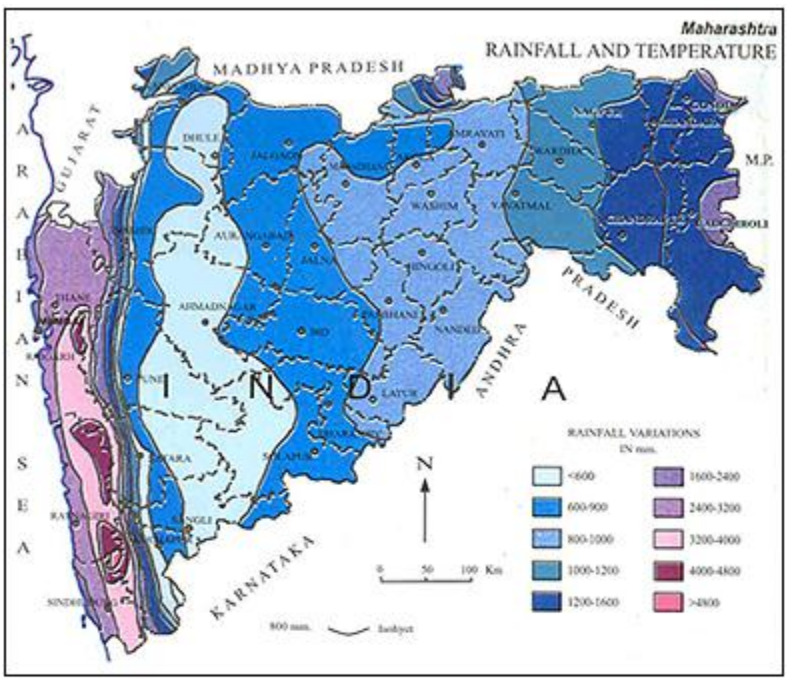


Figure 2: Variation of Temperature and Rainfall in Maharashtra

About a quarter of India's drought-prone districts are in Maharashtra, with 73% of its geographic area classified as semiarid. The drought-affected districts of Maharashtra are mainly Ahmednagar, Solapur, Nashik, Pune, Sangli, Satara, Aurangabad, Beed, Osmanabad, Dhule, Jalgaon, and Buldhana which account for 60% of the net sown area and lie in the rain shadow region east of the Sahayadri mountain ranges in Maharashtra and the adjacent Marathwada region. Maharashtra experienced severe and successive years of drought in 1970-1974 and 2000-2004.

Since intensity of rainfall plays a crucial role in the occurrence of floods particularly flash floods, monthly extreme rainfall for few regions in Maharashtra have been analyzed and it reveals significant increase in the extreme rainfall (Jamir et al. 2008). Mumbai also witnessed massive floods in July, 2005 where over 900 people perished and over Rs 450 crores of damage of property was reported. The State has also experienced many cyclones in the past and more recently in November 2009 the cyclone Phyan inflicted damages related to strong winds, the un-seasonal heavy rainfall and tidal surge.

Name of the Zone	**Geographical Spread**	**Climatic Conditions**	**Soil type**	**Crop and Cropping Pattern**
South Kokan Coastal Zone				
Very high Rainfall Zone With Laterite Soils 15.30 To 18.50 N Latitude 72 45 to 74 50 E Longitude	Comprises Mainly of Ratnagiri and Sindhudurg Districts Total Area 13.20 Lakh Ha.	Daily Temp. > 20 C. throughout year. May Hottest > 33 C. Average annual rainfall: 3105 mm in 101 days	Laterite . Acidic, Poor in Phosphorous Rich in Nitrogen and Potassium	Rice is the Major Crops i.e. 39% of Cultivated Area. Ragi 2nd Imp Crop; Pulses like Horsegram Grown on Residual Moisture. Oilseeds- Niger / Sesamum, Horticultural Crops and Spices
North Kokan Coastal Zone				
Very High Rainfall Zone with Non Lateritic Soils 17 52 to 20 20 Latitude 70 70 to 73 48 E Longitude	Comprises of Thane & Raigad Districts. Total Area 16.59 Lakh. Ha	Avg. Daily Temp 22-30c. Average annual rainfall: 2607 mm in 87 Days.	Coarse & Shallow. Acidic, rich in Nitrogen, Poor in P and K	Rice is Major Crop 40,600 Lakh. Ha Vari 19,600 Ha. Pulses, vegetables, oilseeds, fruits
Western Ghat Zone				
Western Ghat Zone /Ghat Zone Narrow Strip Extending from North to South along the Crest of Sahyadri Ranges	It includes Hilly High Lying Terrains of Kolahapur, Satara, Pune, Ahmednagar & Nasik Districts & Small Area of Sindhudurg District.	Maximum Temp. 29-39 C.Minimum Temp 13-20 C. Average annual rainfall: 3000 to 6000 mm.	Warkas' i.e. Light Laterite & Reddish Brown. Distinctly Acidic, Poor Fertility Low in P & K	25% Area is under Forest. Principal Crops- Rice/Ragi/Kodra & Other Cereals. Rabi Jowar, Gram, Groundnut, Niger. Sugarcane Major Crop. Well Suited Conditions for Rainfed Crops.
Transition Zone -1				

Name of the Zone	Geographical Spread	Climatic Conditions	Soil type	Crop and Cropping Pattern
Sub Montane Zone/Transition Zone 1 Located on Eastern Slopes of Sahyadri Ranges	Spreads over 19 Tahsils of five Districts Viz. Nasik, Pune, Satara, Sangli & Kolhapur. Area 10289 Sq Km	Maximum Temperature 28-35 C and Minimum 14-19 C Average annual rainfall: 700-2500 mm.	Soils Reddish Brown to Black Tending to Lateritic. Well Supplied in Nitrogen but Low in P & K	Mainly Dominated by Kharif Cereals, Groundnut & Sugarcane. Rabi Crops are taken where there are Deep Soils & Moisture holding Capacity.
Transition Zone -2				
Western Maharashtra Plain Zone/Transition -2 It is A Wider Strip Running Parallel to Eastern Side of Sub Montane Zone.	Tahsils of Dhule, Ahmednagar, Sangli & Central Tahsils of Nasik, Pune, Satara & Kolhapur. Geographical Area 17.91 Lakh Ha.	.Maximum Temperature 40 C & Minimum 5 C. Well Distributed Rainfall 700 to 1200 Mm.	Soils Greyish Black. Moderately Alkaline Fair in NPK content. Good for Irrigation.	The Zone is Predominantly a Kharif Tract Suitable for Single Rainfed Crop. Principal Crops Grown-Kharif & Rabi Jowar, Bajra, Groundnut, Wheat, Sugarcane, Udid, Tur Gram & Ragi.
Scarcity Zone				
Western Maharashtra Scarcity Zone/Scarcity Zone	This Zone Covers Geographical Area of 73.23 Lakh Ha. The Gross & Net Cultivated Area is 58.42 Ad 53.0 Lakh Ha. Respectively.	Suffers from very low & uncertain rainfall. Drought Once in Three Years. Maximum Temperature 41 C Minimum -14-15 C Less Than 750mm in 45 Days.	The Soils are Vertisol. Poor in Nitrogen, Low to Medium in Phosphate & Well Supplied in Potash .	Two Cropping Systems. During Kharif Shallow & Poor Moisture Retentive Soils are Cultivated. Medium Deep, Moisture Holding Capacity Soils are Diverted to Rabi Cropping. Kharif Cropping 25-30%. Crops -Bajra, Jowar , Groundnut, Safflower, Pulses etc. Productivity is Rather Low in Both the Seasons.
Assured Rainfall Zone				

Name of the Zone	Geographical Spread	Climatic Conditions	Soil type	Crop and Cropping Pattern
Central Maharashtra Plateau Zone /Assured Rainfall Zone	Parts of Aurangabad, Jalna Beed & Osmanabad; Major Parts of Parbhani & Nanded & Complete Latur Buldhana & Parts of Akola, Amravati, Yavatmal, Jalgaon, Dhule & Solapur. Area: 75 Lakh Ha.	Maximum Temperature 41 C minimum Temperature 21 C 700 to 900 mm 75 % Rains Received in all Districts of the Zone.	Soil Colour Ranges from Black to Red. Type- 1) Vertisols 2) Entisols & 3) Inceptisolsph 7-7.5	Jowar is a Predominant Crop Occupying 33% of Gross Cropped Area Cotton-22.55%. Oilseeds 5.17%, Pulses 7.63 %. Kharif Jowar/Bajra Followed by Gram, Safflower. Area under Paddy is increasing. Pulses -Tur, Mung, Udid, Gram & Lentils. Oilseeds- Groundnut, Sesamum Safflower & Niger. Sugarcane & Summer Crops are taken on availability of Irrigation.
Moderate Rainfall Zone				
Central Vidarbha Zone /Zone of Moderate Rainfall There are Five Sub-Zones of Central Vidarbha Zone Based on Climate Soil & Cropping Pattern	Entire Wardha, Major Parts of Nagpur Yavatmal 2 Tahsils of Chandrapur & Parts of Aurangabad, Jalna Parbhani & Nanded. Largest Agroclimatic Zone 49.88 Lakh Ha Geographical Area	Maximum Temperature 33-38 C Minimum Temperature 16-26 Caverage Daily Humidity 72 % in Rainy Season , 53 % in Winter & 35% in Summer 1130 Mm..	Black Soils Derived from Basalt Rock. Medium to Heavy in Texture Alkaline in Reaction. Low Lying Areas are Rich and Fertile.	Cropping patterns Involves Cotton, Kh.Jowar, Tur, Wheat other Pluses & Oilseeds
Eastern Vidarbha Zone				
Eastern Vidharbha Zone/High Rainfall Zone With Soils Derived from Parent Material of Different Crops. There are Four Subzone Based on Climate, Soilsand Crop Pattern	Entire Bhandara & Gadchiroli and Parts of Chandrapur and Nagpur Districts. Geographical Area is 32.7 Lakh/Ha. and with Almost 50% Under Forest.	Max. temperature 32 To 37 C. Min. Temperature 15 to 24 C. 950 to 1250 mm on Western Side. 1700 mm on Extreme East Side. Rainy days: 59	Soils Derive from Parent Rock Granite, Gneisses and schists. Brown to Red in colour.	Paddy is Predominant Crop in Bhandara. Rb. Pulses- Gram, Lathyrus. Paddy is followed by Rb. Jowar Pulses and Oilseeds.

2.4 Ecology

With almost 60116 square km of land area under forest and tree cover, Maharashtra is a State that is rich in forest resources. Gadchiroli, Amravati and Chandrapur are the districts that have the maximum area of forest cover (Figure 3).

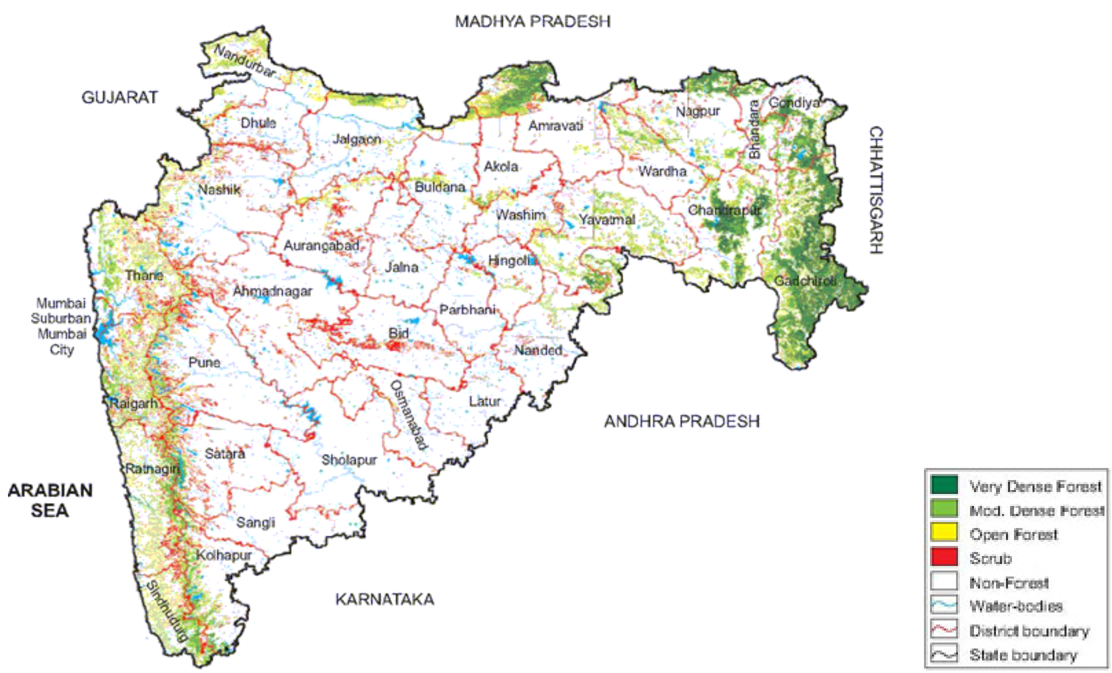


Figure 3: Forest Cover Map of Maharashtra

The Sahyadri mountain range of Maharashtra is recognised as one of the world's 34 biodiversity hotspots. 11 districts and 67 taluks fall in the Sahyadri range. While Western Maharashtra region has dry deciduous forests, the Konkan region has semi-evergreen to evergreen forests. The prolonged dry season of 6 to 8 months has characteristic impacts on the species composition in comparison with forests to the south of Maharashtra.

Excellent mangrove areas can be found in estuaries and creeks along the coast of Maharashtra, particularly in Thane, Raigadh, Navi Mumbai, Ratnagiri, and Sindhudurg. The types of mangroves found in the State are summarized in Table 1. However, these are threatened by habitat loss due to human interference, pollution, Khar land bunding, aquaculture, grazing, and other commercial uses. As a result, the area under mangroves has decreased by approximately 40% over the last 25 years.

Table 1: Types of mangroves found in coastal Maharashtra

Mangrove type	**Example / Location**
River-dominated estuarine mangroves	Vashishthi, Shastri and Savitri estuaries
Mangroves along tidal estuaries and creeks	All along Maharashtra coast
Backwaters, bays or very small tidal inlets	Valvati near Shreevardhan (Raigadh)
Island vegetation	Bucher and Elephanta Islands around Mumbai

The most important wetlands of Maharashtra in terms of biological and socioeconomic value are identified in Table 2 (National Wetland Atlas of Maharashtra 2010), while the lakes identified under the National Lake Conservation Programme and the State Lake Conservation Programme are listed in Table 3.

Table 2: Important wetlands of Maharashtra

Region	Wetland
Vidarbha	Lonar Lake, Buldhana district Navegaon Notified Wetland, Gondia district
Marathwada	Nathsagar Notified Wetland, Aurangabad district Yeldari Reservoir, Parbhani district
Western Maharashtra	Nandur Madhyameshwar Tank, Nashik district Ujani Reservoir, Solapur district

Table 3: Lakes in Maharashtra under the National and State Lake Conservation Programmes

Lakes under State Lake Conservation Programme	Lakes under National Lake Conservation Programme
Sonegaon Lake, Nagpur Lakes in Aitwade Khurd Peer Lake, Nandurbar Moti Lake, Sawantwadi-1 and 2 Ganesh Lake, Sangli, Miraj& Kupwad-1 and 2 Gandhisagar Lake, Nagpur Sonegaon Lake, Nagpur Shrimant Jaysingrao Lake, Kagal Dedargaon Lake, Dhule Yamai Lake, Pandharpur Charlotte Lake, Matheran Hanuman Lake, Nagpur	Powai Lake, Mumbai Nine lakes in Thane Mahalakshmi Lake, Vadgaon Rankala Lake, Kolhapur Varhala Devi Lake, Bhivandi Siddeshwar Talav, Solapur

3. Climate change trends and model-based projections for Maharashtra

3.1 Introduction: All-India trends and projections

The report of the Indian Network for Climate Change Assessment (INCAA) presents climatic trends and projections for 2030s for 4 regions – Western Ghats, Coastal regions, North-Eastern region, and Himalayan region (GoI, 2007). The future projections have been generated using the Hadley Centre Regional Climate Model, PRECIS, at a 50x50 km resolution for a considered development pathway which assumes a not so drastic change in the climate and is more appropriately termed as a mid-estimate scenario, A1B. Regarding past trends, the Report observes that mean temperatures all over India have shown a significant increase of 0.51°C during 1901–2007 (Figure 1). Accelerated warming has been observed in the recent periods of 1971–2007. Significant increases in temperatures have been observed during the winter and post-monsoon seasons. Steeper increases in minimum temperatures have been observed compared to maximum temperatures (GoI, 2007).

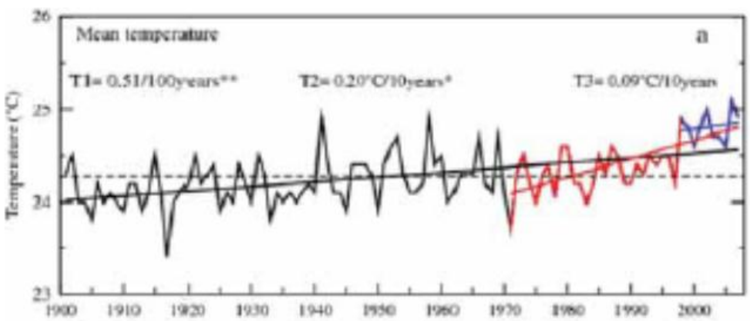


Figure 1: All India annual mean temperature variations during 1901-2007

In case of rainfall, the Indian monsoon does not show any significant trend with a slight decrease when averaged over 1871-2009. There is an epochal trend observed in the rainfall over this period with a clear deficit observed in the early part of the century which is followed by a period of excess rainfall and then again net deficit post 1960. Spatial distribution and analysis over time shows not so significant increasing and decreasing rainfall trends over different parts of India but most of it is not statistically significant.

Regional climate projections indicate a 3 to 7% overall increase in all-India summer monsoon precipitation in the 2030s with respect to 1970s. In the western coastal region the same trend is repeated, increase is projected to be to in the tune of 6 to 8% i.e., of 69 to 109 mm. While summer monsoon is projected to increase in the region the summer and winter rainfall observes a net decline (Figure 2).

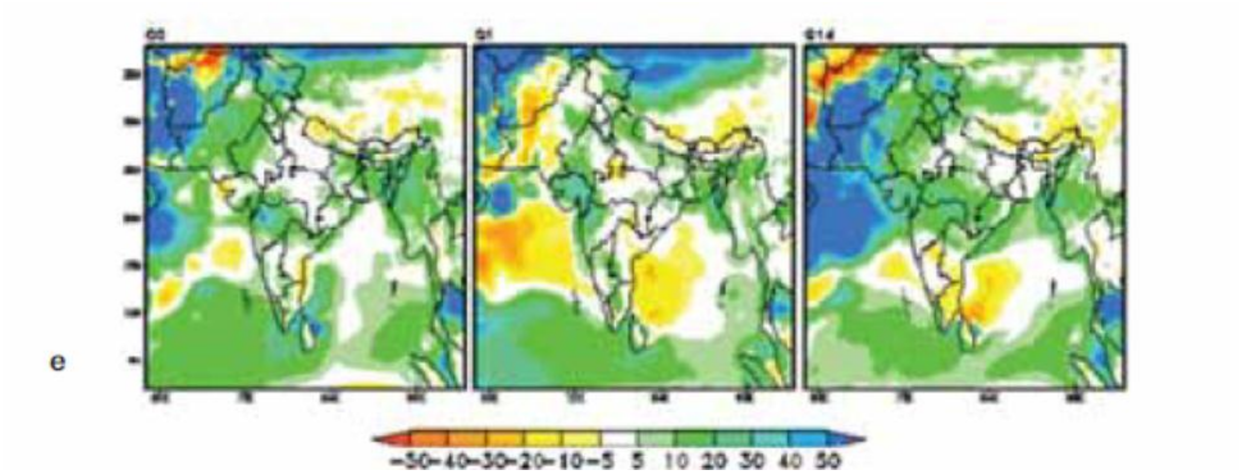


Figure 2: Projected changes in summer monsoon rainfall in 2030s with respect to 1970s (GoI, 2007)

India-wide warming is being projected for 2030s to the scale of 1.7 to 2 degree C. Winter temperatures increases may be more prominent compared to summer temperatures (Figure 3).

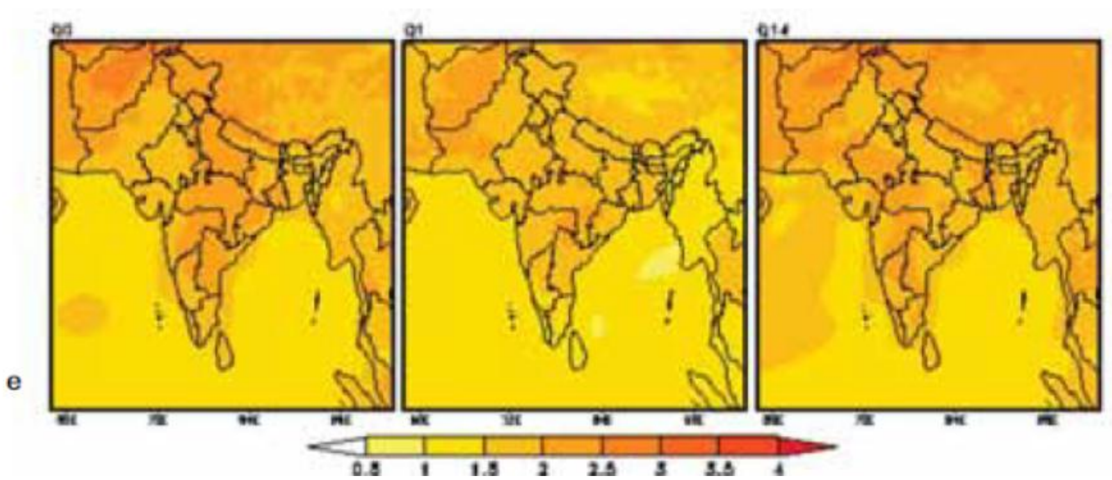


Figure 3: Projected changes in surface air temperatures in 2030s with respect to 1970s (GoI, 2007)

India's second NATCOM to the UNFCCC (GoI, 2012) also presents projected changes in the climate for the A1B scenario at a 50 km resolution for 2020s, 2050s and 2080s. The annual mean surface temperature increases have been projected to be in the range of 3.5 to 4.3^{o}C. Rainfall increases has been indicated in all simulations to the scale of 9, 15 and 16 % with regional variations (Figures 4 and 5).

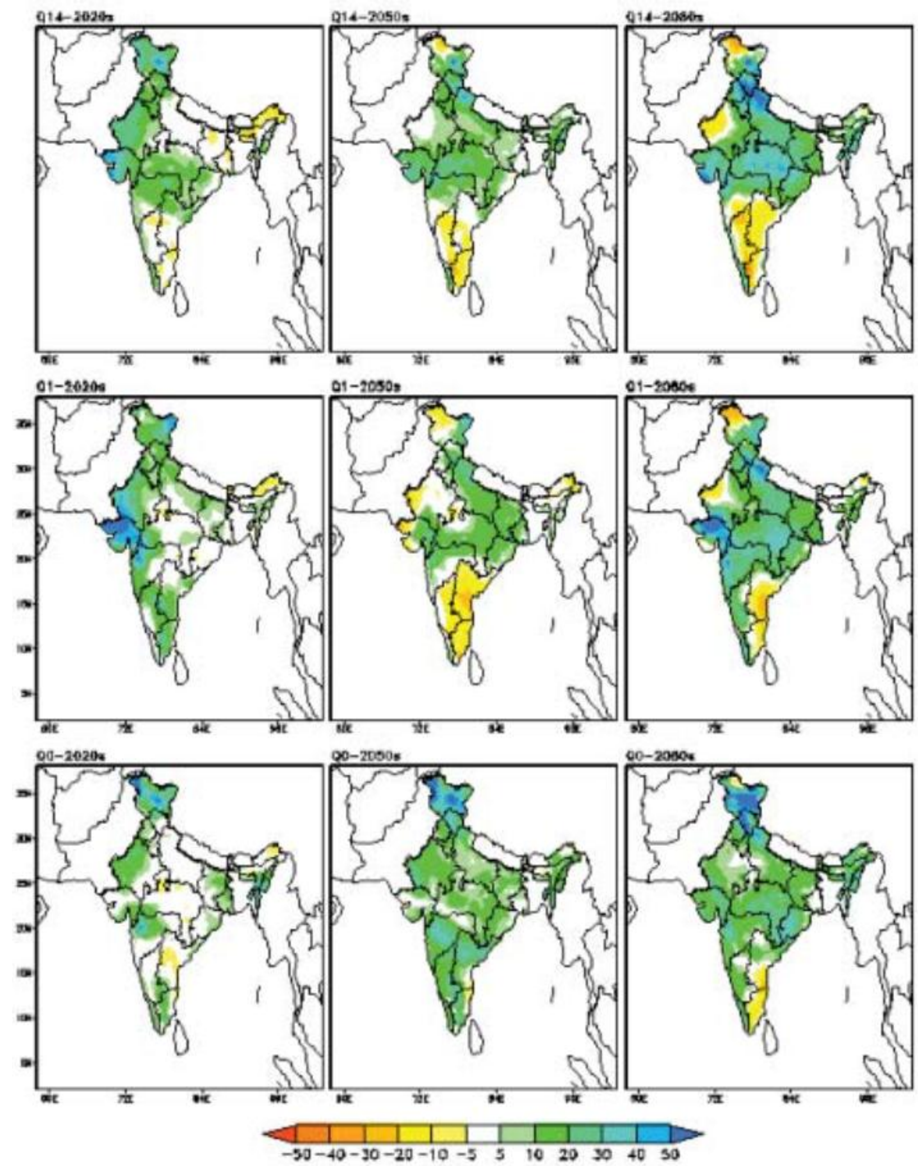


Figure 4: Model projections of mean monsoon rainfall for 2020s, 2050s and 2080s with respect to baseline (1961-1990) (GoI, 2012)

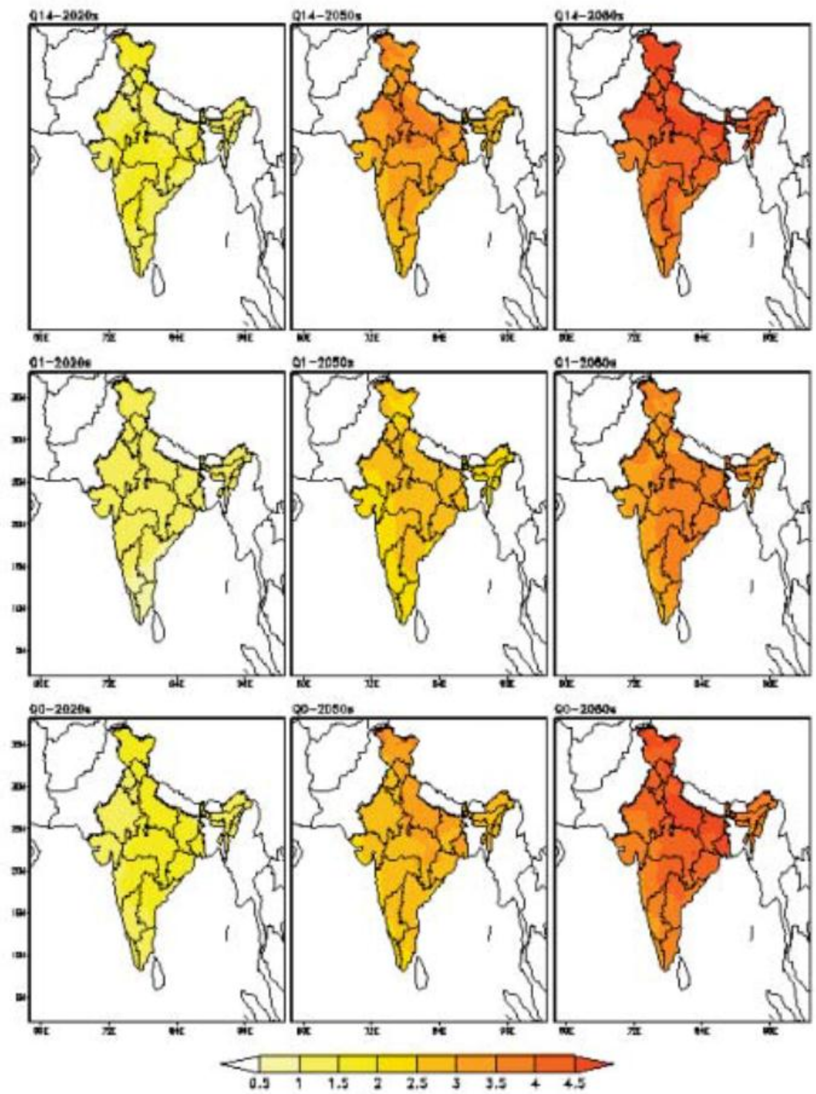


Figure 5: Model projections for mean surface air temperatures for 2020s, 2050s and 2080s with respect to baseline 0f 1961-1990 (GoI, 2012)

3.2 Methodology for climate modelling for Maharashtra

Climate models are essential tools to assess the climate variability and change in the climate. Though climate change is global in nature, the impacts are felt at local scales, and play a prominent role in addressing the vulnerability to climate change in these regions. This raises the importance of regional climate projections. In this study, we have generated regional climate projections for the State of Maharashtra using the state-of-art regional climate models developed by the UK Met Office. The regional climate model used in the study is coupled with the global model of UK Met Office (Hadley Centre Climate Model Version 3-HadCM3) using a one-way nesting approach, in which global information is passed on to the regional model but the regional model does not pass regional information back to the global model (Bhaskaran et al., 1996). While the domain selection for identifying the best fit domain for the projections and model performance and correlation with observations has been done and the report had been submitted earlier, this report aims to focus on the projections for the State for the 2030s.

3.2.1 Objectives

To develop climate projections for the State of Maharashtra using high-resolution regional climate models at 25km x 25km resolution with unique ensemble approach and assess the changes in the temperatures and precipitation patterns in the State both in the past and for future time periods. The UKMO RCM has been used to generate the results. Specific objectives include:

1. Analysing the past climatological records of temperature and rainfall
2. Validation of the model simulated data with observations
3. Assessing the changes in temperatures and precipitation in future with respect to the past

3.2.2 Data Sources

Four ensemble simulations using PRECIS model for A1B scenario for baseline (1970-2000) time period and future time period (2021-2040) has been used for the analysis. Observation data used for validation of these models are from India Meteorological Department (IMD), 1x1 degree gridded dataset (Rajeevan et al., 2006) of rainfall from 1951-2007 and temperature (mean, maximum and minimum temperature, Srivastava et al., 2009) for 1969-2005. Daily mean climatologies of district wise datasets (IMD, 2010) of number of rainy days, maximum temperature, minimum temperature and mean temperature values have been used to assess the district wise variation in the number of rainy days during JJAS and the variability in temperature.

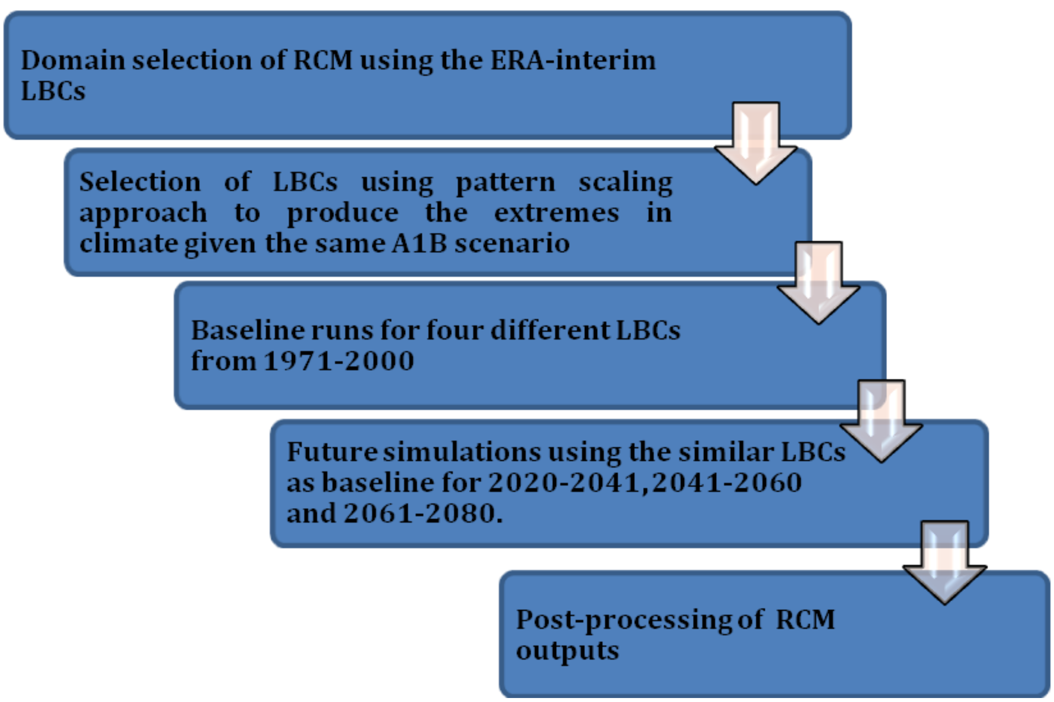


Figure 6: Framework approach for climate model assessments over Maharashtra region.

3.3 District-wise analysis of observational data

The observed monthly climatological temperature along with the number of rainy days has been analysed for 26 districts. Only those districts are taken where the values for both the parameters are available. The district-wise data is taken from the daily district-wise normals of meteorological parameters dataset from National Climate Centre, Indian Meteorological Department. Daily normals of 7 meteorological parameters, viz. rainfall, maximum temperature, minimum temperature, mean temperature, relative humidity, total cloud amount and wind speed. The rainfall normals have been prepared for 524 districts using 50 years of data (1941-1990) and normals of other parameters have been prepared for 445 districts using 30 years of data (1971-2000). The basic data have been quality controlled before calculating district wise normals.

Figure 7 shows the climatological district normals of number of rainy days in a month for different districts in Maharashtra. It is clearly seen that the districts of Ratnagiri, Sindhudurg, Thane, Mumbai City and Kolhapur have more number of rainy days as compared to other districts. On the other hand, the districts of Ahmednagar Sholapur and Bhir are in the range of least number of rainy days. Figure 7 also shows that the number of rainy days is high in few districts, medium in some and low in other districts. These districts with high variability in rainfall could also be the regions where the extreme rainfall during a monsoon season can occur. Thus, it is important to represent these patterns of rainfall even in the models in order to be able to provide reasonable results for future.

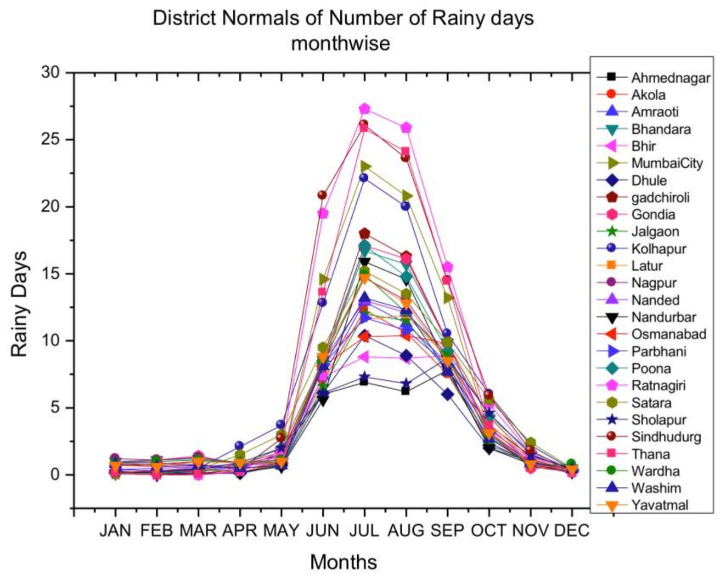


Figure 7: District normals for climatological mean of number of rainy days per month

The district normals of monthly mean temperature at 2m for different districts over Maharashtra shows that temperature has a bimodal structure with maximum temperature in March to May for almost all the districts of Maharashtra with high temperatures in few districts where the rainfall is also less compared to other regions. Satara region has the lowest temperature compared to many other districts and this might be due to the topography and the seasonal monsoon rainfall reaching early over this region.

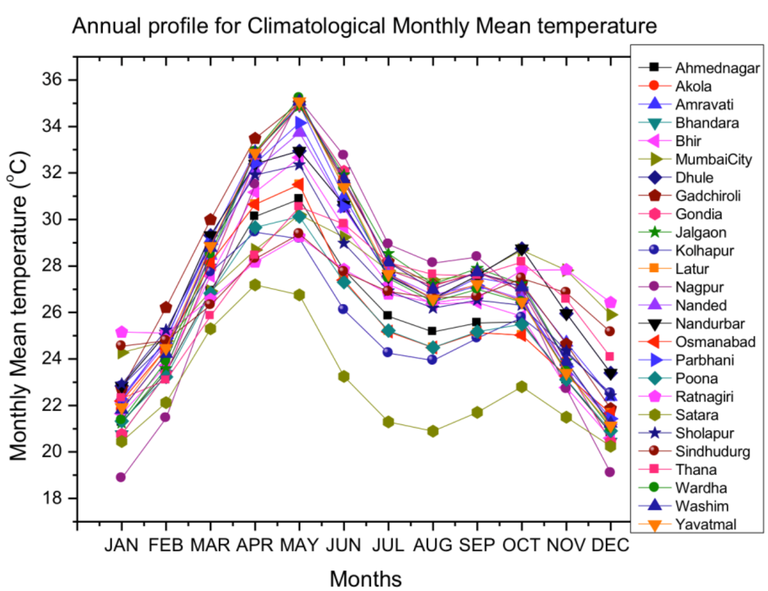


Figure 8: District normals of monthly mean temperature at 2m for different districts of Maharashtra.

The observations show that rainfall has large variation in different districts of Maharashtra as compared to the temperature that show equal distribution in the seasonal cycle. Hence, understanding the patterns of rainfall in model baseline and future simulation becomes critical for assessing future climate impacts.

3.4 Model validation

Figure 9 shows the comparison of baseline runs from four different ensembles and ensemble mean with observed gridded data from IMD for JJAS rainfall climatology over Maharashtra state. The spatial variability shows that most of the major prominent features of rainfall characteristics are well captured by the models. The ensemble mean rainfall (Figure 9b) is able to capture the decrease in rainfall over the rain shadow region, the high rainfall variability over the Western Ghats region and also on the eastern parts of Maharashtra. Ensemble mean of the PRECIS RCM is able to represent the spatial pattern of mean temperature at 2m well compared to observations (Figure 10). However, the coarser resolution of the observational data limits the representation of the Western Ghats rainfall variability, due to which the rain shadow region variability on the Western region is different in observations and models. The range of temperature in model and observations also show that the model is able to obtain the magnitude in all the districts similar to observations except for the rain shadow region and in the Western Ghats.

Figure 11 and Figure 12 shows the annual spatial variability of maximum and minimum temperature climatology over the Maharashtra state. The maximum temperature variability is shown to have similar pattern and range of maximum temperature in all districts except for a few over Dhule, Nandurbar, Chandrapur and Gadchiroli region. The spatial analysis of minimum temperature over Maharashtra shows that minimum temperature variability of models is well represented as compared to observations (Figure 12). However, the model seems to attain much lower temperatures than observed in few regions of Nashik, Pune and Satara.

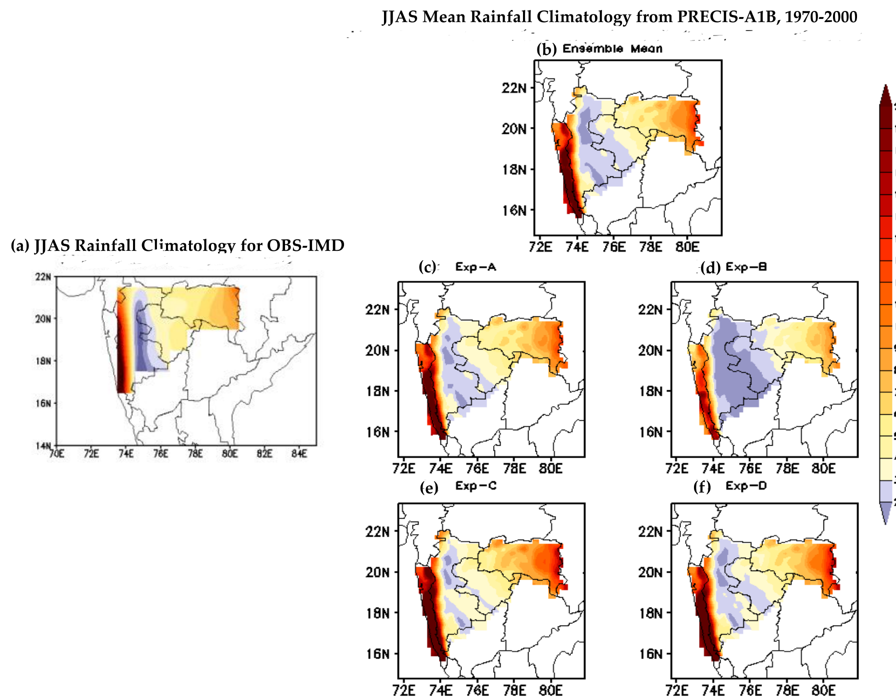


Figure 9: Spatial variability of JJAS mean rainfall of (a) Observations, (b) Ensemble mean of the four model runs, (c) Ensemble –A, (d) Ensemble-B, (e) Ensemble-C and (f) Ensemble-D.

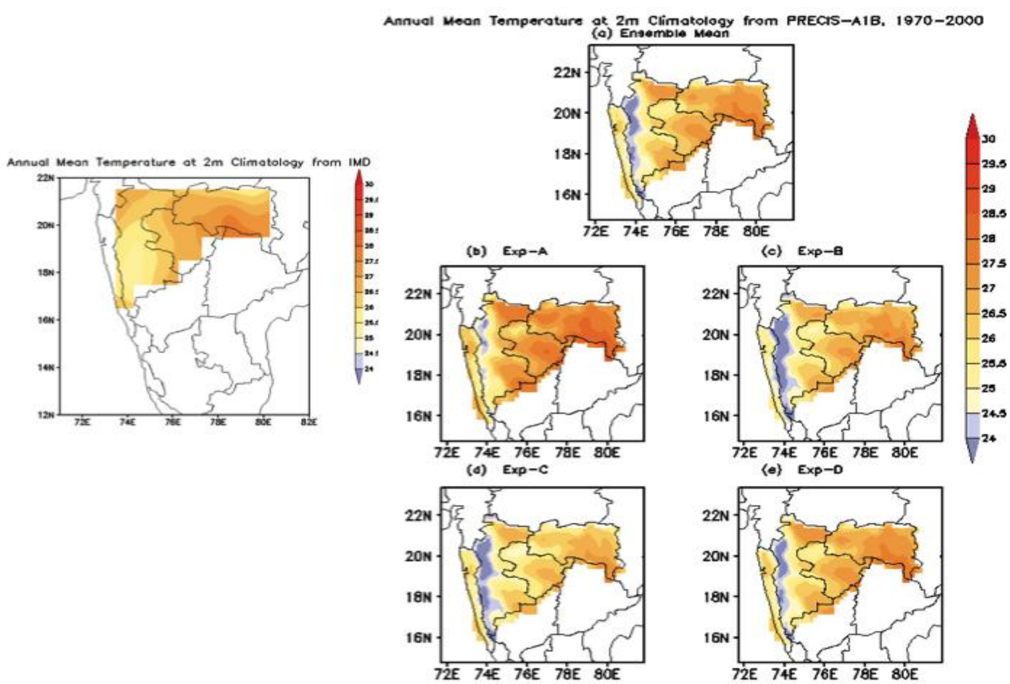


Figure 10: Spatial variability of Annual Mean Temperature at 2m of (a) Observations, (b) Ensemble mean of the four model runs, (c) Ensemble –A, (d) Ensemble-B, (e) Ensemble-C and (f) Ensemble-D.

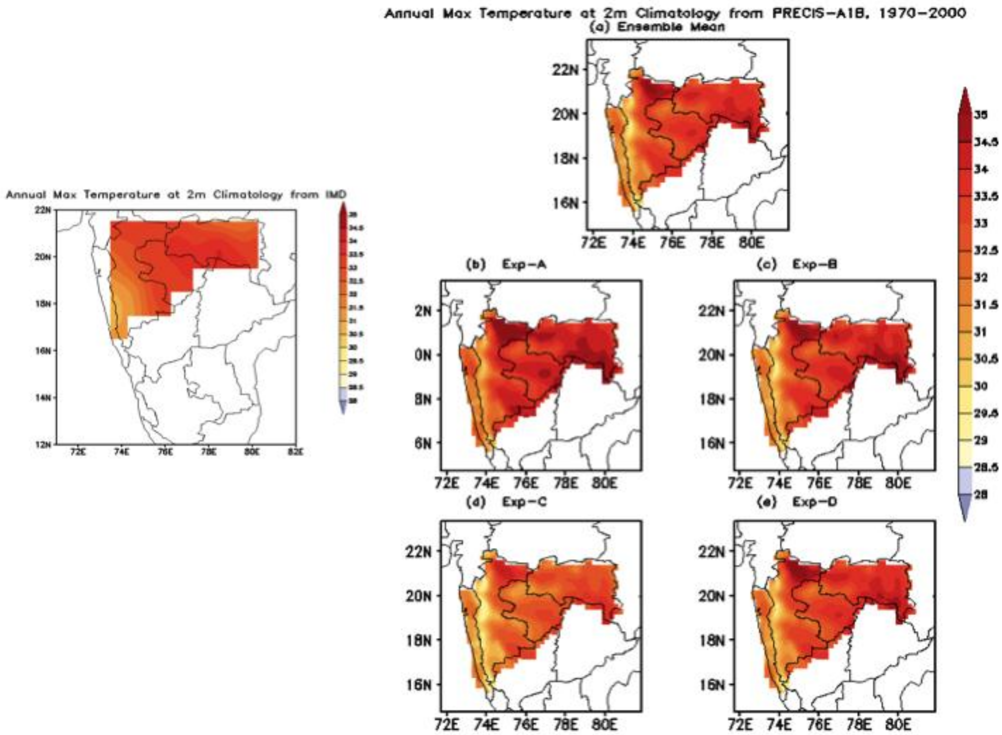


Figure 11: Spatial variability of Annual Mean Maximum Temperature of (a) Observations, (b) Ensemble mean of the four model runs, (c) Ensemble –A, (d) Ensemble-B, (e) Ensemble-C and (f) Ensemble-D.

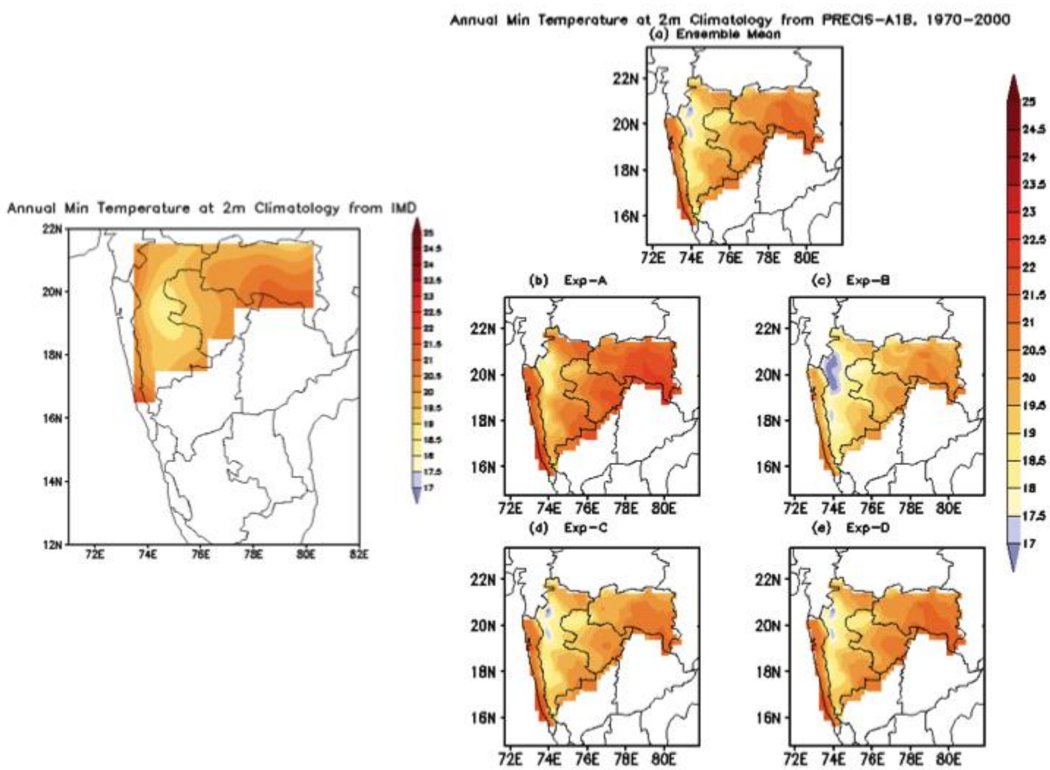


Figure 12: Spatial variability of Annual Mean Minimum Temperature of (a) Observations, (b) Ensemble mean of the four model runs, (c) Ensemble –A, (d) Ensemble-B, (e) Ensemble-C and (f) Ensemble-D.

The comparison of daily rainfall climatology over the state of Maharashtra for different ensembles with observations (Figure 13) shows that the ensembles-mean has a correlation coefficient value of 0.94 with observations.

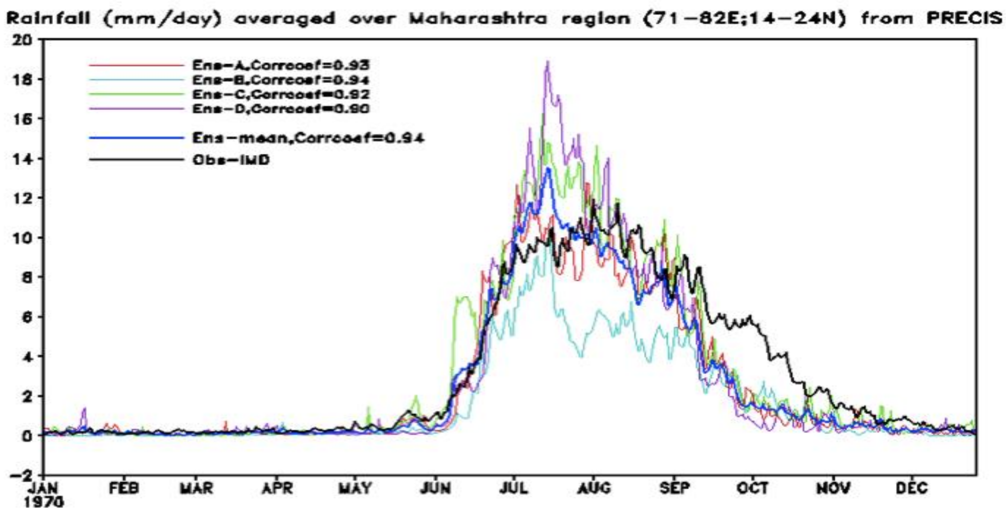


Figure 13: Daily climatology of rainfall over Maharashtra region using PRECIS model (Ensemble mean – thick blue; Observations, IMD- thick black; Experiment-A –thin red line; Experiment B- think cyan line; Experiment C- thin green line; Experiment D- thin violet line).

Individual ensemble members also show high correlation coefficient with the observations showing that the given set of models are able to represent the seasonal mean rainfall variability much better than many of the global and regional climate models (IPCC 2007; Rupakumar et al 2006; Yadav et al., 2010).

3.5 Future Regional Climate Projections over Maharashtra for 2030s

3.5.1 Rainfall projections

The spatial variability of rainfall in 2030s compared to baseline (Figure 14) shows that the spatial pattern is similar in 2030s as compared to observations and baseline, with increase in rainfall in magnitude but no change in spatial distribution. As we know, the climate change signal might increase the mean and variance of rainfall but might not affect the spatial variability or location of rainfall maximum (IPCC, 2007). The percentage increase in rainfall in 2030s with respect to baseline (Figure 15) shows that a few regions in Maharashtra will experience increase in rainfall, especially the north-central Maharashtra region compared to east, west and southern Maharashtra.

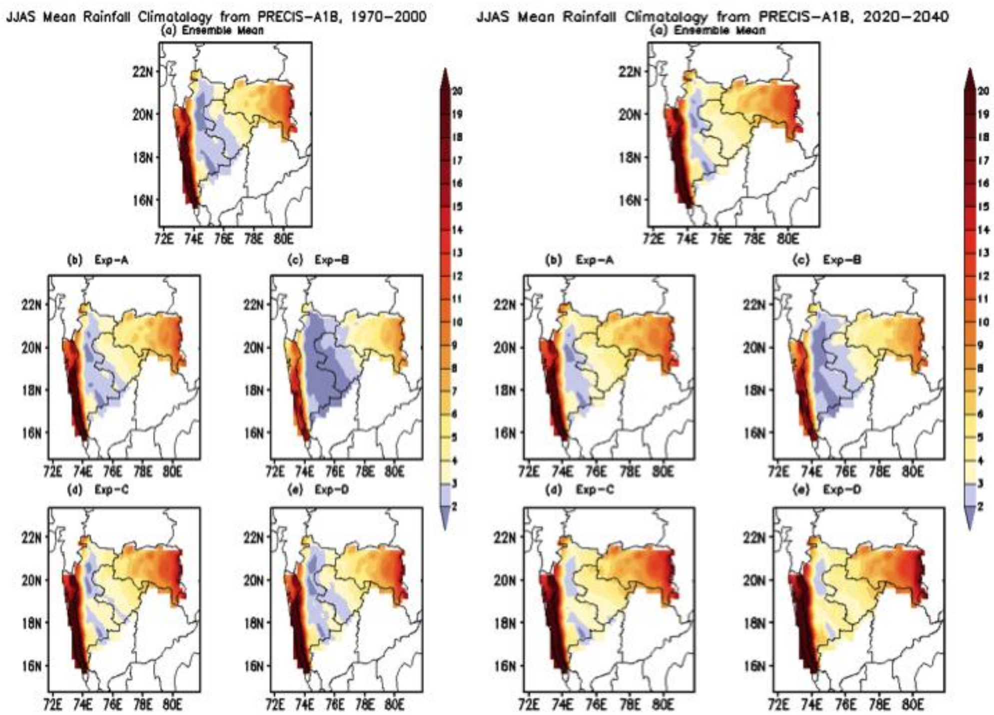


Figure 14: Spatial variability JJAS mean Rainfall climatology (in mm/day) for (left) Baseline and (right) 2020-2040 time period.

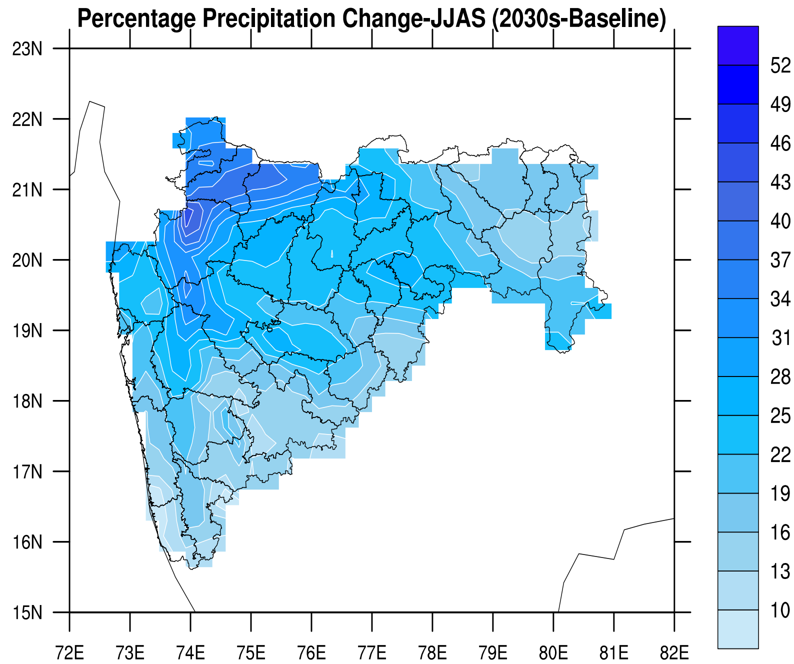


Figure 15: Percentage change in Rainfall (2030s-Baseline)/Baseline using 2030s and baseline climatology, showing percentage increase/decrease in rainfall over a given region.

3.5.2 Extreme rainfall projections

Though the percentage of change in rainfall provides the regions of increase or decrease in rainfall, it is essential to map the percentage increase in extreme rain events over Maharashtra region in 2030s with respect to the baseline. Previously many studies (Goswami *et al.*, 2006; Kothawale *et al.*, 2010; Krishnamurthy *et al.*, 2009; and Turner *et al.*, 2009), showed that the frequency and intensity of rainfall extremes is increasing over many regions of India. IPCC (2007) and Alexander et al (2006) have also showed using daily observations that the increase in extreme events has become more frequent in many parts of the world. Following the extreme event index definition by the Expert Team on Climate Change Detection and Monitoring Index (ETCCDMI) and Alexander et al (2006), we define the extreme wet days in 2030s using R99ptot index with respect to the baseline (Figure 16a).

To understand the extremes in rainfall we have developed an extreme rainfall index, which shows that the extreme rainfall (99th percentile) intensity increases in all regions, and with large amount of increase in Aurangabad and northern regions of Nashik division compared to Konkan belt and Vidharbha region.

Extreme rainfall index is calculated by considering the baseline data and calculation the 99^{th} percentile of rainfall at every grid for the JJA time period, this dataset is considered as a reference for calculation the future rainfall extremes compared to baseline Rainfall of future > Rainfall of 99p for baseline is considered at every grid and the index then calculates the ration of R99p for future/ sum of total precipitation for future. Thus providing extremely wet day proportion of rainfall in future compared to baseline (Karl 1999; Peterson 2001; Alexander 2006; IPCC 2007).

The extreme rainfall index shows an increase in all regions with large amount of increase in Aurangabad and northern regions of Nashik division compared to Konkan belt and Vidharbha region. It essentially means that Aurangabad and northern Nashik regions would have higher contribution from extreme rainfall in their total rainfall of 2030s.

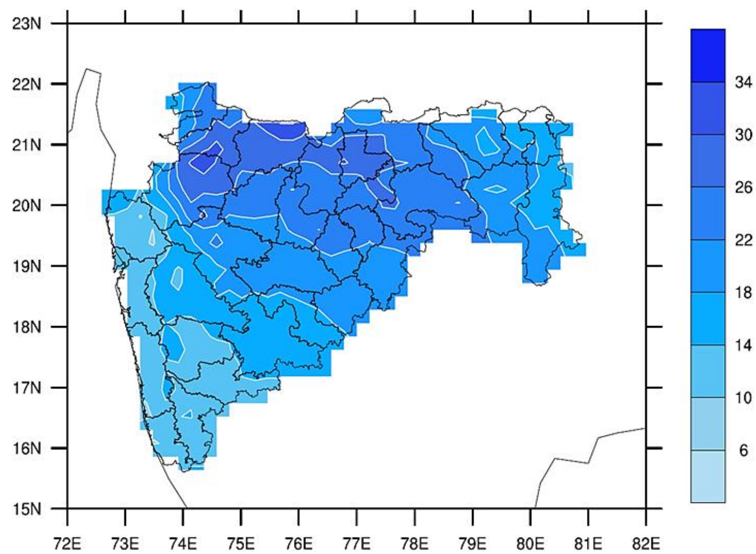


Figure 16a: Extreme Rainfall R99ptot index with respect to baseline over Maharashtra region.

Figure 16b shows low rainfall or dry day index for the Maharashtra state. Threshold based Rainfall index to understand rainfall variability over the Maharashtra region. We have developed a simple index based on quantile[11] values for rainfall over Maharashtra region. (Note here that this method is different from the traditional method of quantifying dry days where the consecutive dry days with rainfall being 0mm/day are considered and the number of days with rainfall being zero is accumulated.) The method considers rainfall values for each grid and the 1% quantile value, which will vary across the region of Maharashtra due of heavy precipitation regions in the west and dry regions in the central. The next step is to find the days of rainfall at every grid where the rainfall is less than 1% quantile of the baseline at the same grid. Thus, we can validate if there is an increase or decrease in the number of days when the rainfall values are less than the number of days in baseline.

The spatial variation of low rainfall days follows the analogy in the extreme rainfall plot with regions of heavy rainfall showing less dry day index. Figure 16b shows the variability of threshold based rainfall index for 2030s summer season (June-July-August), it was found that there is an increase in the number of days of rainfall less than 1% quantile threshold over south central Maharashtra region. The numbers denote a mean for 30 years for the future and the values show that there is less number of days with rainfall less than 1% quantile in the northern

[11] Quantile stands for "each of any set of values of a variate which divide a frequency distribution into equal groups, each containing the same fraction of the total population." (Wikipedia). For example: In simple terms these are values at a given grid when the values of rainfall in the grid is populated as a frequency distribution and the values that lie below certain quantile (in our case 1% quantile is considered, these are in the lower end of the tail distribution).

Maharashtra region, if we compare this with extreme 99% rainfall index (Figure 16a), these are the regions where the possibility of percentage increase in rainfall is higher and also extremes.

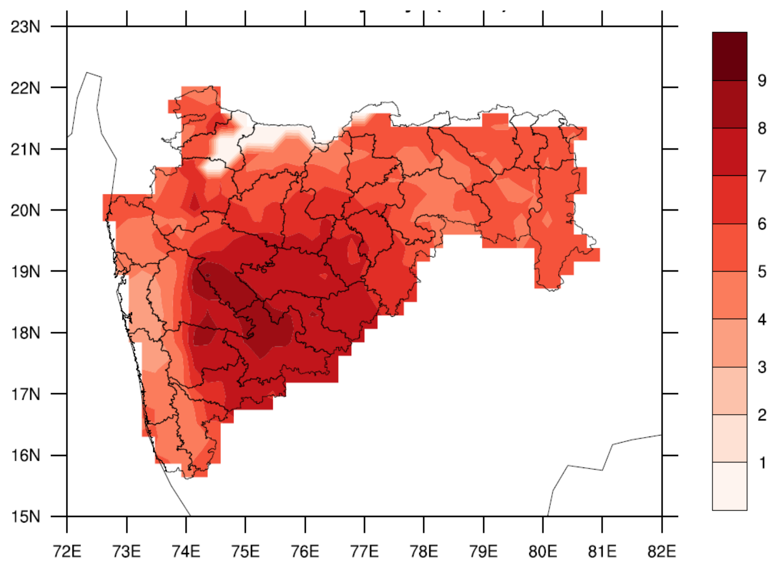


Figure 16b: Low rainfall days or dry days index with respect to baseline over Maharashtra region.

3.5.3 Temperature projections

The temperature change in 2030s over different regions of Maharashtra with the baseline and IMD data is a major concern for the impact studies. The seasonal cycle of climatological mean temperature, maximum temperature and minimum temperature at 2m level (Figure 17) shows that mean temperature at 2m follows similar trend as observations in baseline in the pre-monsoon months; however after the onset of the monsoon the model seems to cool more than observations. The mean temperature at 2m for 2030s shows a slight increase in temperature of 1-1.5^{o}C during all seasons. Similar kind of increase is also found in the minimum temperature and maximum temperature with approximately 1-2^{o}C increase in 2030s compared to baseline.

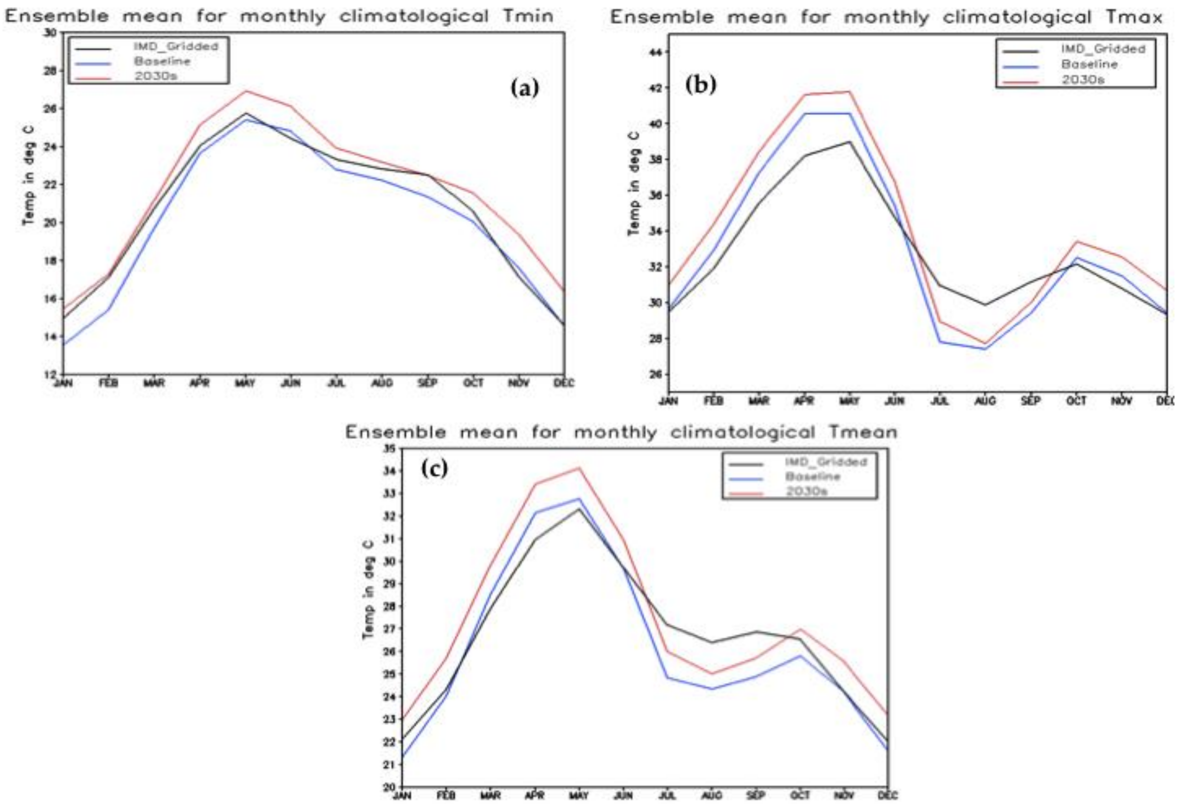


Figure 17: Comparison of seasonal cycle of mean temperature at 2m, maximum temperature at 2m and minimum temperature over Maharashtra region using PRECIS model (Ensemble mean – thick blue; Observations, IMD- thick black).

The spatial pattern of increase in mean temperature at 2m in 2030s with baseline (Figure 18) shows that spatially there is a difference in warming in a few regions compared to other regions. Annual Mean temperature is found to be 1.2-1.5 degrees centigrade increase in the Vidarbha region, Marathwada and Nasik regions as compared to Pune and Konkan region where the increase in temperature was found to be 1-1.2 degrees centigrade. Similarly, the increase in maximum temperature and minimum temperature were found to be high in a few regions and less increase in few other regions. Figure 19 shows that similar to the mean temperature, maximum temperature at 2m is also found to increase around 1-1.2 degrees centigrade in the Vidarbha, Marathwada regions compared to Nashik, Pune and Konkan regions where the increase in temperature ranges from 0.5-1 degrees centigrade. The increase in minimum temperature (Figure 20) was found to be more than maximum temperatures and in similar regions as mean temperature and maximum temperature.

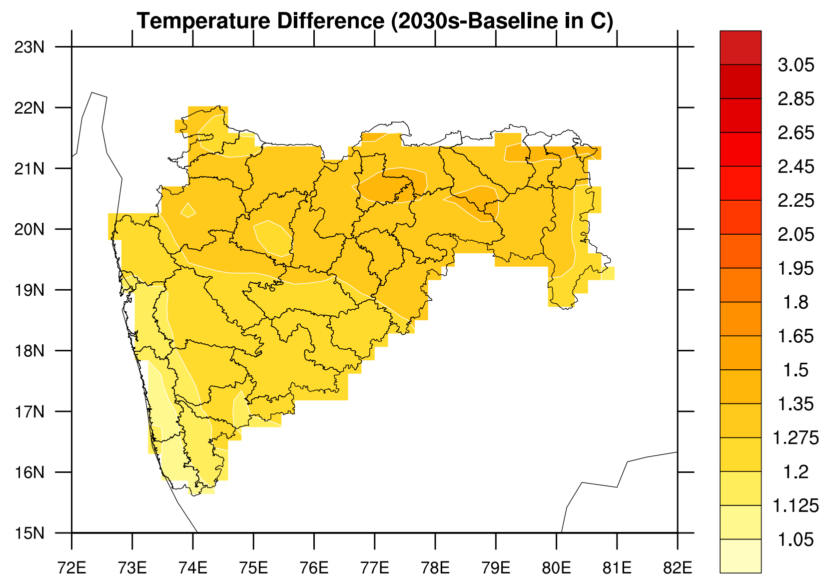


Figure 18: Difference in Annual mean temperature at 2m (2030s – Baseline), considered here are ensemble means for baseline and 2030s.

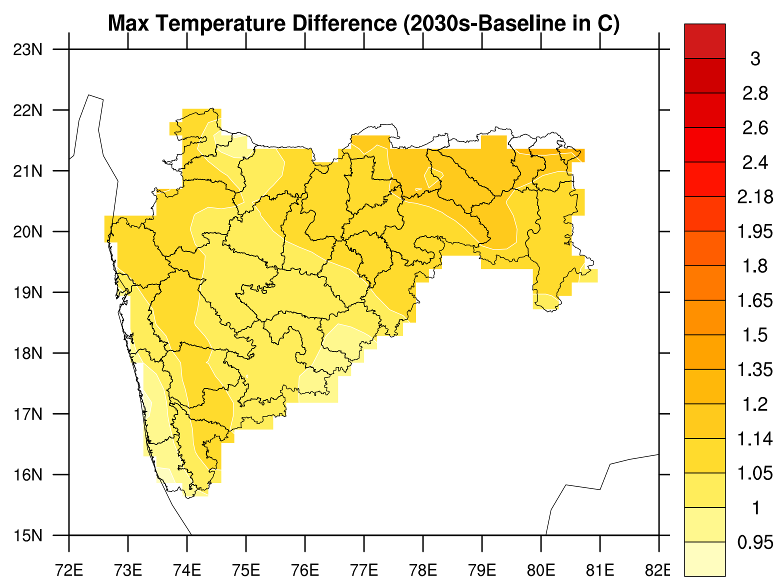


Figure 19: Difference in Annual mean maximum temperature at 2m (2030s – Baseline), considered here are ensemble means for baseline and 2030s.

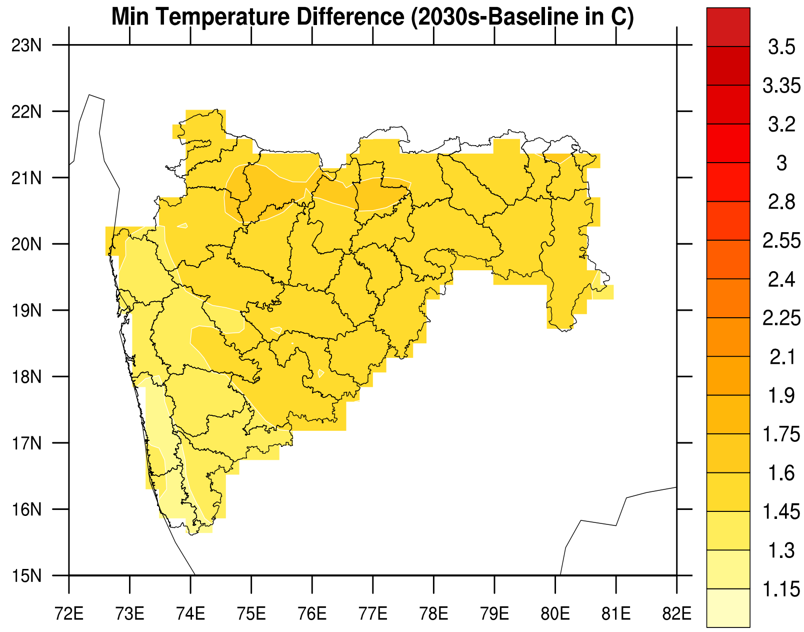


Figure 20: Difference in Annual mean minimum temperature at 2m (2030s – Baseline), considered here are ensemble means for baseline and 2030s.

3.5.4 Extreme temperature projections

To understand the extreme temperatures possible over different regions of Maharashtra, we have developed a warm nights at 90th percentile index.

Warm nights index also called as Tn90p by ETCCDMI (IPCC 2007; Alexander et al 2006) is calculated using minimum temperature, the 90th percentile of minimum temperature for the baseline data set is calculated and Tmin of future > 90p of tmin baseline is calculated which provides the increase in warm nights over different grid points when compared to the baseline of the same dataset.

The percentage of increase in warm nights in future with respect to 90th percentile of baseline minimum temperature (Figure 21) shows that warm nights are increasing more in the Konkan and Pune and Nashik division compared to the Vidarabha, Marathwada and Aurangabad regions. The regional average of warm night index per time period for the eastern region, western region and total region shows that there is an increase in warm nights which is more prominent after 2030s in all the regions (Figure 22).

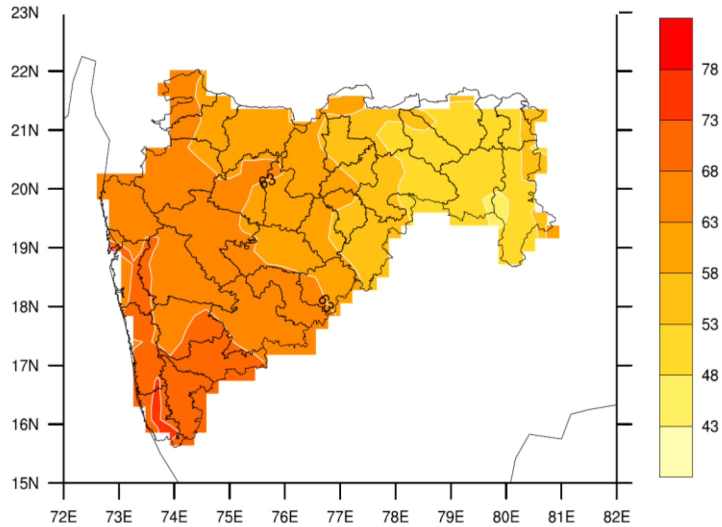


Figure 21: Warm nights index Tn90p in 2030s (annual mean climatology) with respect to baseline.

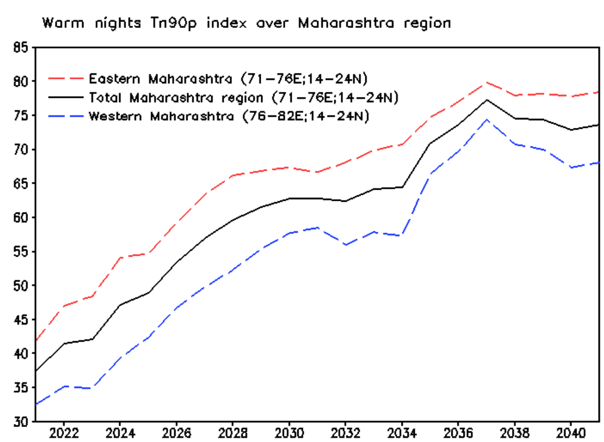


Figure 22: Spatial average of warm nights index (Tn90p) over Total Maharashtra region (71-82E;14-24N); Eastern Maharashtra region (71-76E;14-24N) and Western Maharashtra region (76-82E;14-24N).

In order to understand the changes in temperature and moisture variability over a given region, we have developed a temperature humidity index called as Heat Index [12] following the

[12]Heat Index : an index that combines air temperature and relative humidity in an attempt to determine the human perceived equivalent temperature- how hot it feels, termed as the felt air temperature

definition proposed by Lans 1990; Steadman 1979 and addressed the changes in Heat Index over Maharashtra region in baseline and future.

We have defined the Heat Index following the NOAA definition (Steadman 1979), for assessing the human comfort due to variability in temperature and humidity in a given region.

$$HI = -8.7847 + 1.6114\,T + 2.3385\,RH - 0.1461T * RH - 0.0123 * T^2 - 0.0164RH^2 + 2.2117e^{-3}T^2RH + 7.2546e^{-4}TRH^2 + 3.5820e^{-6}T^2RH^2$$

Relative Humidity (%)	temperature (°C) 27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
40	27	28	29	30	31	32	34	35	37	39	41	43	46	48	51	54	57
45	27	28	29	30	32	33	35	37	39	41	43	46	49	51	54	57	
50	27	28	30	31	33	34	36	38	41	43	46	49	52	55	58		
55	28	29	30	32	34	36	38	40	43	46	48	52	55	59			
60	28	29	31	33	35	37	40	42	45	48	51	55	59				
65	28	30	32	34	36	39	41	44	48	51	55	59					
70	29	31	33	35	38	40	43	47	50	54	58						
75	29	31	34	36	39	42	46	49	53	58							
80	30	32	35	38	41	44	48	52	57								
85	30	33	36	39	43	47	51	55									
90	31	34	37	41	45	49	54										
95	31	35	38	42	47	51	57										
100	32	36	40	44	49	54											

Caution
Extreme Caution
Danger
Extreme Danger

Equivalent temperature (Heat Index) values vis-a-vis the actual temperature and humidity values.

Some possible health effects of Heat Index equivalent temperatures

Temperature range	Possible effects
27–32 °C	Caution: fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps.
32–41 °C	Extreme caution: heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke.
41–54 °C	Danger: heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity.
over 54 °C	Extreme danger: heat stroke is imminent.

Figure 23 refers to the annual mean Heat Index for baseline and 2030s, showing higher temperatures over the coastal region and Vidarbha region as compared to central Maharashtra region. Thus the coastal regions and Vidarbha region also show a large variability not only in the warm nights but also in heat index, indicating that these regions might be prone to more extremes in temperature.

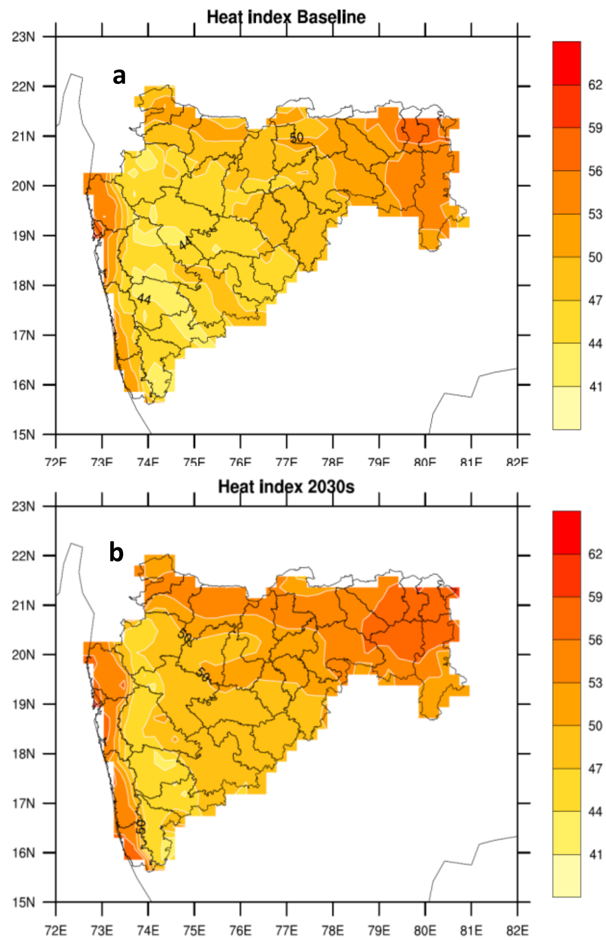


Figure 23: Heat Index for (a) baseline (1971-2000) and (b) 2030s (averaged for 2021-2040).

3.6 Future Regional Climate Projections over Maharashtra for distant future time periods: 2050s and 2070s

The projections for percentage increase in rainfall in 2050s and 2070s with respect to baseline (Figures 24 and 25) shows an overall increase in rainfall over the entire state of Maharashtra. The spatial pattern for the percentage increase in rainfall for 2050s is similar to that of 2030s over Southern, Eastern and Northern East Maharashtra. Over Central Maharashtra and parts of South East Maharashtra the projections for 2050s show a larger percentage increase of rainfall with respect to 2030s (Figure 24). For the projections for distant future time period; 2070s, although the spatial pattern is similar to that of 2030s and 2050s, the intensity of the percentage increase is much higher in regions (North West Maharashtra) that show a higher increase for 2030s and 2050s (Figure 25). The projections for 2070s being a distant future scenario with a large uncertainty should be taken as an indicative measure.

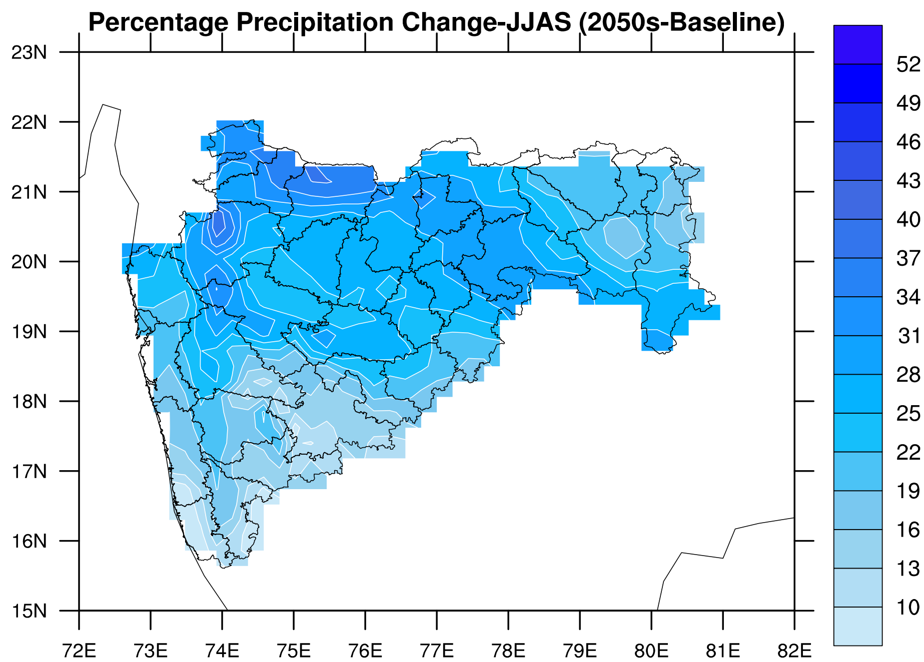


Figure 24: Percentage change in Rainfall (2050s-Baseline) showing percentage increase/decrease in rainfall over a given region.

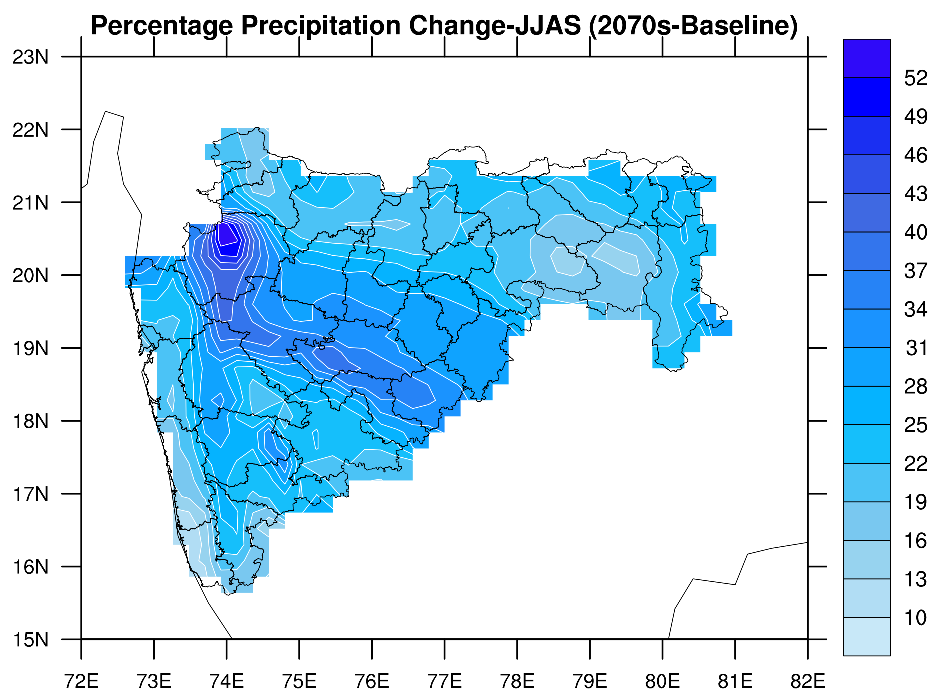


Figure 25: Percentage change in Rainfall (2070s-Baseline) showing percentage increase/decrease in rainfall over a given region.

Likewise for 2030s, the spatial pattern of increase in mean temperature at 2m in 2050s and 2070s with respect to baseline (Figure 26) also show that there is a difference in warming in a few regions compared to other regions. For 2050s the annual mean temperature shows an increase of around 1.8-2.1 degrees centigrade in the Vidarbha, Marathwada, and Nasik regions as compared to Pune and Konkan region where the increase in temperature is projected at about 1.5-1.8 degrees centigrade. This pattern is seen for 2070s as well but the overall increase in temperature is projected to be between 2.1-3 degrees for the entire state with highest increase projected over Vidarbha region of about 2.8-3 degrees centigrade.

The increase in maximum temperature (Figure 27) and minimum temperature (Figure 28) are also seen to be high in a few regions and less across other regions of the state for 2050s and 2070s time periods. Figure 27 shows maximum temperature projection for 2050s which also follows a similar spatial pattern as compared to 2030s. But the increase in maximum temperature is also found to be higher in 2050s for the Vidarbha, Marathwada regions compared to Nashik, Pune and Konkan regions vis-à-vis their corresponding 2030s projection. The 2070s distant future projection shows a much higher increase in maximum temperature over the entire state with the highest increase projected over the Vidarbha region.

The minimum temperature projections (Figure 28) for 2050s and 2070s show an overall increase of minimum temperature values for the entire state of Maharashtra. Apart from Vidarbha, the Nashik region also shows a considerable increase in minimum temperature values with respect to baseline both for 2050s and 2070s with maximum increase projected of around 3.5 degrees over Eastern Maharashtra.

It is important to note here that the projections for 2050s and 2070s for temperature shown below as well as for rainfall (Figures 24 and Figure 25) should be taken as indicative only based on present scientific understanding and not as an absolute increase for distant future projections.

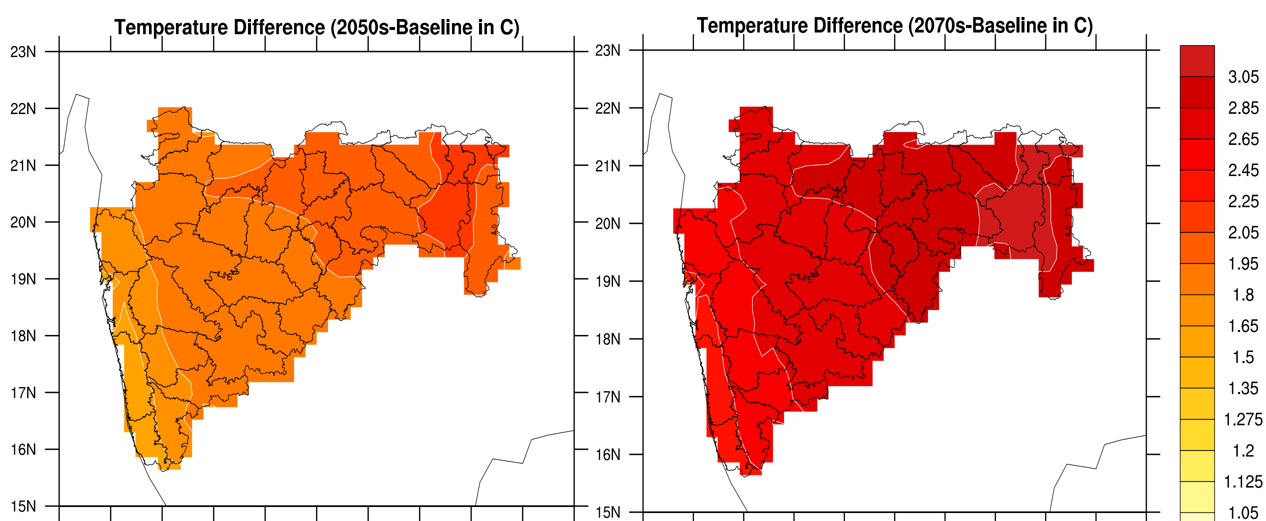


Figure 26: Difference in annual Mean temperature at 2m (2050s & 2070s – Baseline), considered here are ensemble means for baseline and 2050s & 2070s.

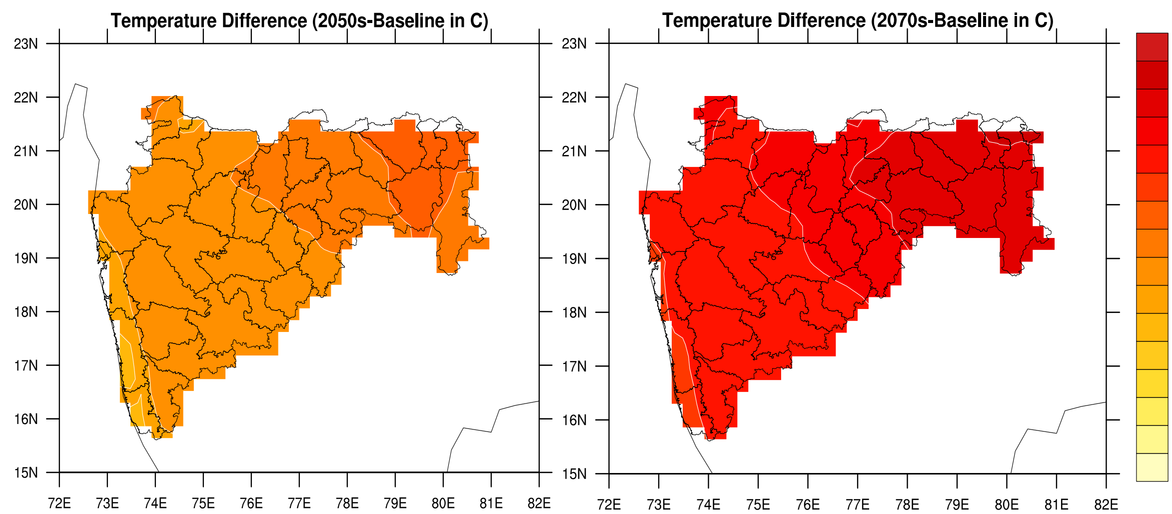


Figure 27: Difference in annual mean Maximum temperature at 2m (2050s& 2070s – Baseline), considered here are ensemble means for baseline and 2030s& 2070s.

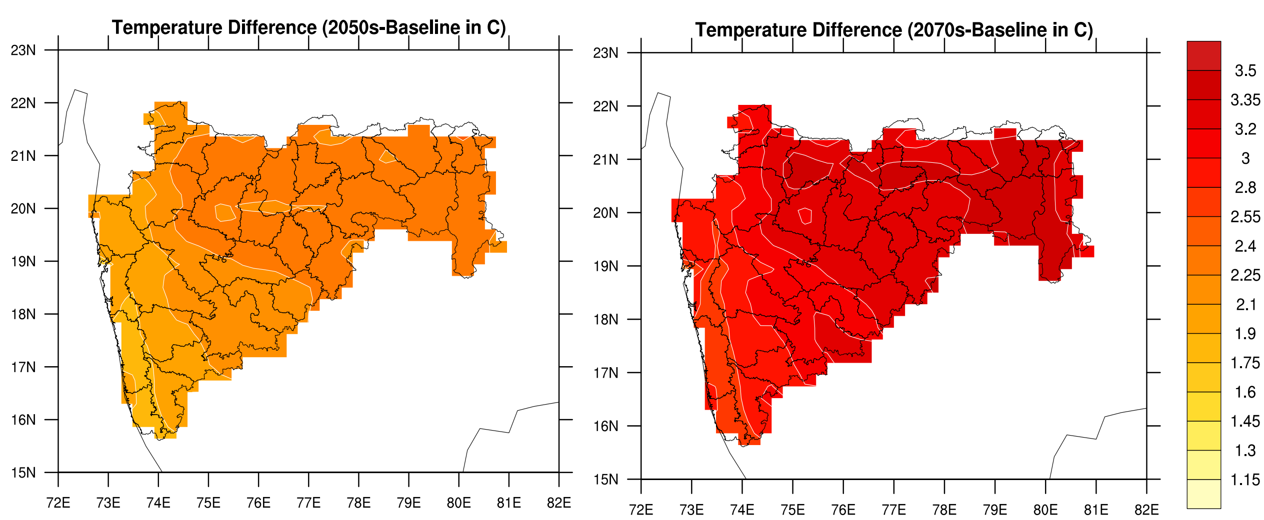


Figure 28: Difference in annual mean minimum temperature at 2m (2050s& 2070s – Baseline), considered here are ensemble means for baseline and 2030s& 2070s.

4. Sea Level Rise (SLR): observed trends and future projections

Climate change may contribute to sea level rise in many parts of world owing to a combination of factors including expansion of oceans and melting of snow and ice sheets. While the impacts of sea level rise are local in nature, its causes are global and can be attributed to non-linear coupled components of the Earth system.

4.1 Historical analysis of sea level rise for Maharashtra coast using tide gauge data

TERI's analysis to assess the historical sea level rise anomaly over the Maharashtra and Mumbai coast has made use of available free data sources *viz.* satellite based and tide gauge at Mumbai Port. A preliminary analysis using the tidal observational record available online at PSMSL[13] over the Mumbai region (18.92N; 72.83E) has been done. The tidal data (Figure 1) shows a high inter-annual variability from the 19th century till date and also an increasing trend over the region. The plot gives a trend of 0.8mm/yr using the tide gauge data alone. Taking into consideration the Glacial Isostatic Adjustment (GIA) corrections of -0.43mm/yr the net sea level rise trend for Mumbai coast is 1.2 mm/yr which is consistent with the value given in MoEF's INCCA report (MoEF, 2010).

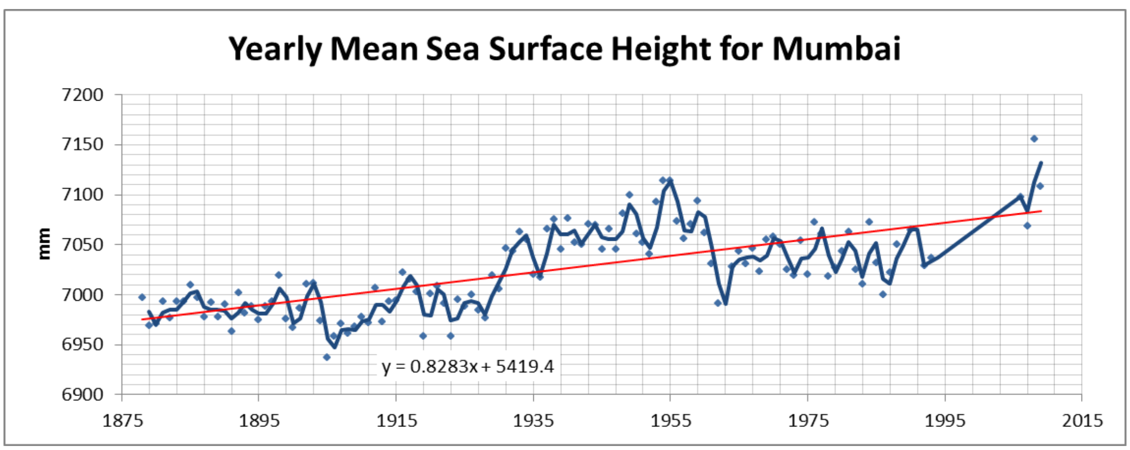


Figure 1. Time series of yearly mean sea surface height (mm), a 2-period moving average have been plotted to cover the data gaps and assess the trend.

The data is available till 2009 and also there is inconsistency in the availability of the dataset (over the time period 2000s). Hence, satellite products from AVISO[14] have been utilized for

[13] PSMSL- Permanent Service Mean Sea Level from National Oceanographic Center; NOC and National Environmental Research Council; NERC

[14] AVISO - stands for Archiving, Validation and Interpretation of Satellite Observational data from NOAA (National Oceanic and Atmospheric Administration), USA.

further analysis of recent trends over the Mumbai region. Also, to address the spatial features of mean sea level over the Arabian Sea region, which has an impact over the Mumbai coast, we have considered the mean sea level anomaly from the AVISO satellite product.

4.2 Analysis of mean sea level using AVISO satellite data

The data consist of maps of Mean Sea Level Anomaly (MSLA) obtained from a complete reprocessing of Geosat data, which consists of (GeoSAT, ESR-1, Jason-1) over the period of interest from December 1992 – May 2009. There is also one map every 7 days over a period of 2 years for the period mid-December 1986 to late December 1988. They were computed using ERM Geosat data distributed by NOAA. Corrections are applied to the data (tidal and inverse barometer corrections, and radiometer troposphere correction, sea state bias etc.). All the atmospheric corrections are based on NCEP (National Centers for Environmental Prediction) data. Sea Level Anomalies (SLA) were computed using conventional repeat-track analysis and were referenced to a mean from January 1993 to January 1999. The mapping is performed using the sub-optimal space/time objective analysis, which takes into account along-track correlated errors. The maps are provided on a Mercator 1/3o grid. Resolutions are in kilometers in latitude and longitude (for e.g.: 37km at the equator to 18.5 km at 60N or S). The unit of the variable is in centimeters. The global data from the AVISO satellite was retrieved for the Arabian Sea to understand the inter-annual variability of SLA. The spatial map averaged over the 2 recent years (2008-09) over the Maharashtra coastal region shows a positive SL anomaly ranging from 3-6 cm over the open coast. The anomaly has been compared to 1993-1999 mean.

The inter-annual variability of the SLA over the Maharashtra coastal region (71-73E; 16-22N) (Figure 2) shows that there is an increase in SLA over the region when compared to the 1993-1998 time period, the anomaly being positive shows (not only in the spatial but also temporal analysis, figure 3) shows that the region experiences a large-scale variability due to mean sea level.

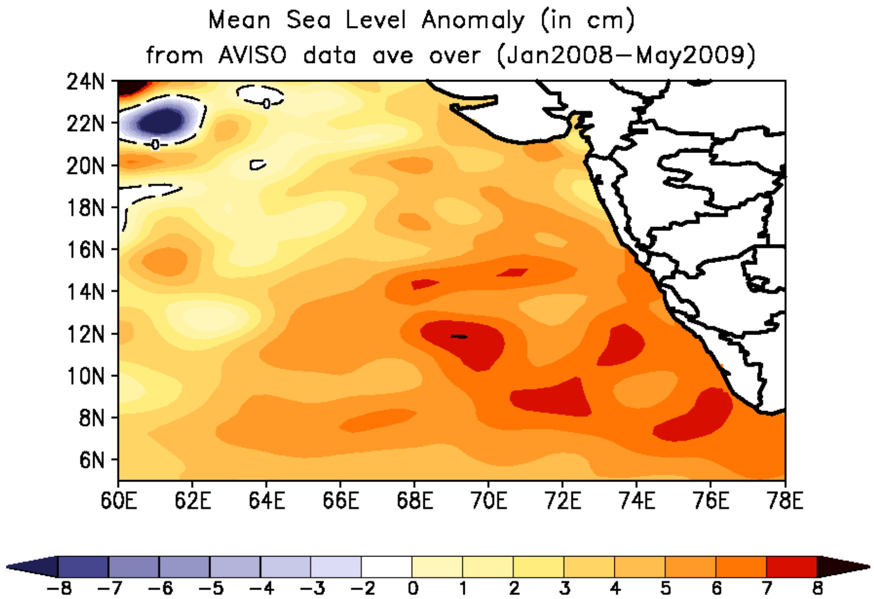


Figure 2: Sea Level Anomaly (in cm) averaged from (Jan2008-May2009) obtained from AVISO satellite.

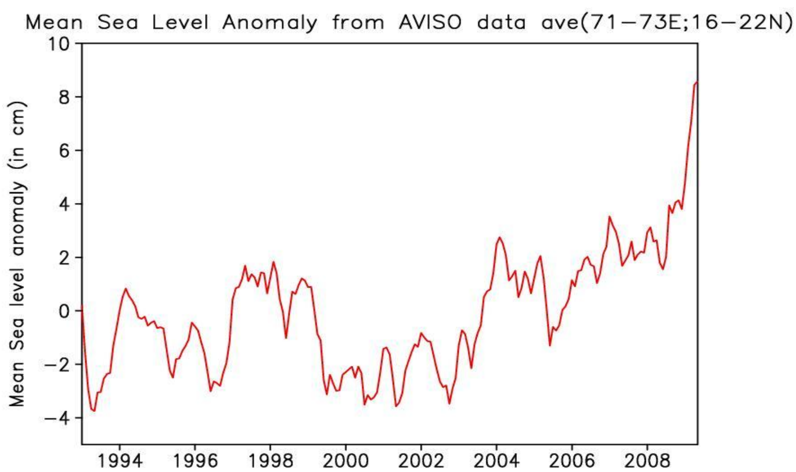


Figure 3: Time series of SLA (in cm) averaged over (71-73E; 16-22N) the Maharashtra coastal region, to address the inter-annual variability a 10-point smooth filter has been used.

To understand the tidal level using the AVISO data Mumbai region was considered as a case study to address the SLA from AVISO over the Mumbai region. The SLA variability over Mumbai (Figure 4) also shows an increase in SLA after 2006 similar to the coastal region average (Figure 3) thereby, indicating that the whole coast is vulnerable to sea level rise.

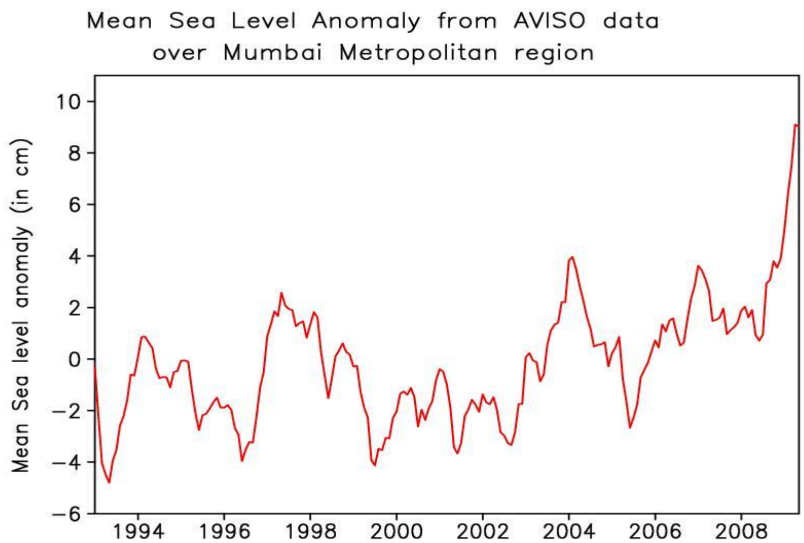


Figure 4: Time series of SLA (in cm) averaged over in and around Mumbai region, in order to address the inter-annual variability of SLA a 10-point smooth filter has been used.

4.3 Assessment of future sea level rise

The recent IPCC Fifth Assessment Report (AR5) provides information on global mean sea level taking into account regional sea level projections, and associated uncertainties. The models used in AR5 are termed as CMIP5 models which are essentially Earth System Models that includes carbon cycle feedbacks, ice sheet, flow, and contributions from freshwater forcings, atmospheric loading and variations within solid Earth (Church et. al., 2013). Confidence in projections of global mean sea level rise has increased since the last assessment report (AR4) because of improved physical understanding of the components of sea level, the improved agreement of process-based models with observations, and the inclusion of ice-sheet dynamical changes (IPCC, 2013).

The global mean sea level rise (SLR) for 2081-2100 relative to 1986-2005 will *likely* (66%-100% probability) be in the ranges of 0.26-0.55m for lower end RCP[15] 2.6, 0.32-0.63m for RCP 4.5, 0.33-0.63m for RCP 6.0 and 0.45-0.82m for RCP 8.5 (*medium confidence*) mitigation scenarios. Figure 5 shows an ensemble mean regional relative sea level change between 1986-2005 and 2081-2100 for all the available RCPs. According to IPCC, 2013 it is *very likely* that over 95% of the world ocean, regional relative sea level rise will be positive.

[15] RCP – Representative Concentration Pathways: denotes the four greenhouse gas concentration (not emission) trajectories adopted by the IPCC AR5. These RCPs describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. (Van Vuuren et. al, 2011)

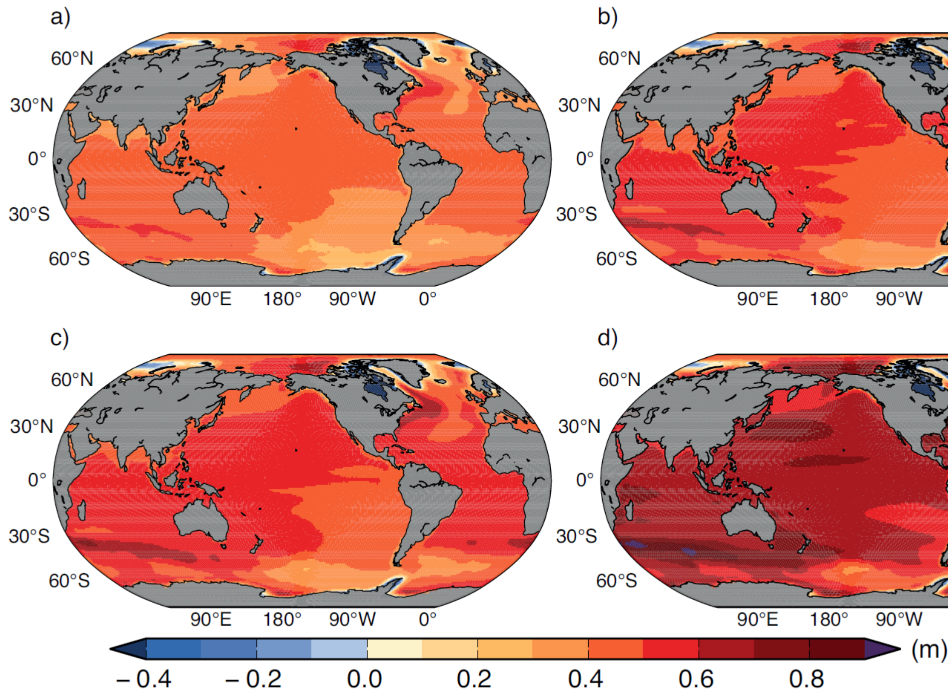


Figure 5. Ensemble mean regional relative sea level change (meters) evaluated from 21 CMIP5 models for RCP a) 2.6 b) 4.5 c) 6.0 and d) 8.5 scenarios for 2081-2100 relative to 1986-2005. The effects of atmospheric loading, land ice, GIA correction and terrestrial water sources are included in each map. (Church et. al., 2013)

In the absence of availability of regional projections, global projections can be used as a first approximation of sea-level rise along the Indian coasts in the next few decades as well as towards the end of the 21st century (MoEF, 2010). About 68% and 72% of the coastlines will experience a relative sea level change within ±20% of the global mean sea level change for RCP 4.5 and RCP 8.5 respectively (IPCC, 2013). Hence, the IPCC assessment of SLR over coastlines has been taken as an approximation of the projected rise over Maharashtra coast for the future time periods.

Sea level changes along the coastlines will range from about 30 cm to 55 cm for RCP 4.5 (lower end) scenario, peaking near 50cm and from about 40 cm to more than 80 cm under the RCP 8.5 (extreme level) scenario, peaking near 65 cm (IPCC, 2013). Also, with reference to figure 6, the regional changes in sea level over Indian west coast sea level reaches values of around 0% to 20% below the global mean estimate.

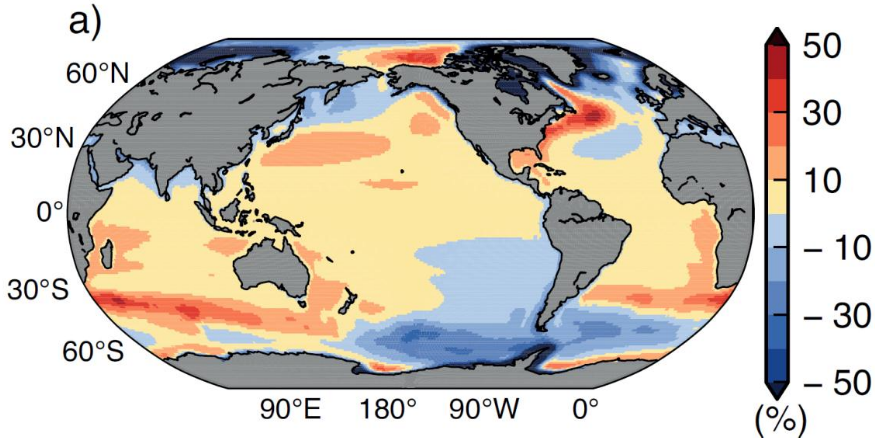


Figure 6. Percentage deviation of ensemble mean regional relative sea level change between 1986-2005 and 2081-2100 from global mean values. Indian west coast is seen to have 0 to -20%.

Figure 7 below shows the trend of Mumbai port from the observed tide gauge data in red (0.8mm/yr). The black line shows a linearly interpolated trend in case we assume BAU without any future climate change. The range in green denotes the projected SLR for coastlines under the low level (RCP 4.5) IPCC AR5 climate change scenario and the range in red denotes the SLR under the relatively higher level (RCP 8.5) IPCC AR5 climate change scenario. It's clearly seen that owing to climate change effects the projected SLR over coastlines is much higher. This accentuates the danger of coastal inundation for the city if high precipitation event, high tides and hydro-meteorological weather events like storms etc. are concurrently observed.

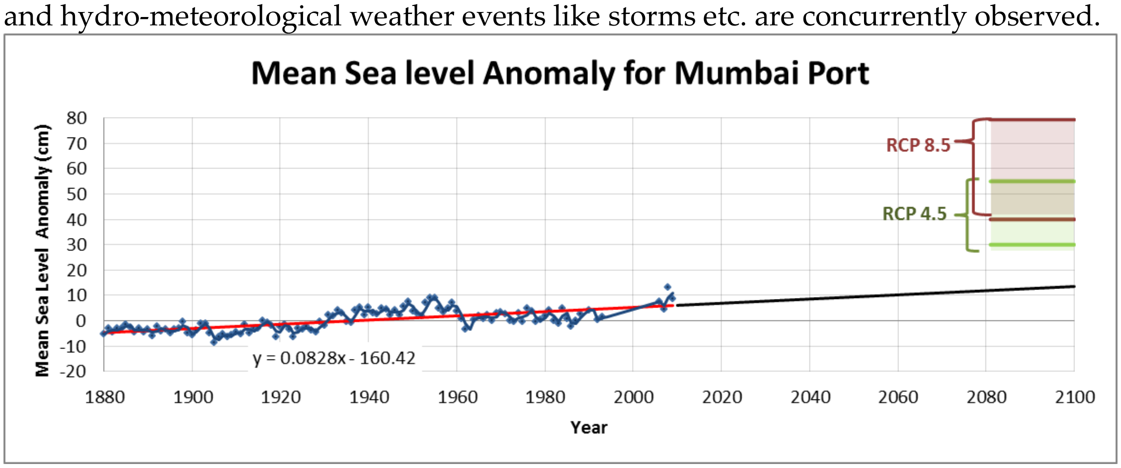


Figure 7. Mean sea level anomaly for Mumbai port relative to relative regional sea level rise projections from IPCC AR5. Blue: mean sea level anomaly using tide gauge data for Mumbai coast, black: observed trend linearly extrapolated in case no climate change, green: projected SLR for coastlines under low level scenario (IPCC AR5), maroon: projected SLR for coastlines under high level scenario (IPCC AR5)

5. Socio-economic projections for 2030s, 2050s and 2070s

5.1 Demographic projections

In this exercise, we have developed two scenarios – viz. the BAU scenario and an Alternative scenario. The BAU is assumed to be the most likely or realistic scenario, while the Alternative scenario was developed as one where dependent variables associated with higher population growth is considered (implying higher vulnerability and stress). Population growth rates depend on fertility, mortality as well as migration.

Accordingly, the BAU scenario considers scenario B of the PFI projections, wherein it is assumed that the States of India with TFR more than that of the replacement level TFR will reach a target level of 1.85 by the end of the projection period, while those States with very low levels of TFR like Kerala and Tamil Nadu are assumed to have a constant TFR at the existing level.

The Alternative scenario assumes that the fertility of India and its States will decline at a much slower pace than in the BAU scenario. It considers scenario A of the PFI projections wherein it is assumed that the States of India with TFR more than that of the replacement level TFR will reach a target level of 2.1 (the replacement level) by the end of the projection period, while those States with very low levels of TFR like Kerala and Tamil Nadu continue to maintain their existing TFR. India's population would be around 2.1 billion in 2101.

In the BAU scenario, Maharashtra's population is expected to be around 150 million by 2051 contributing to 8.81% of the country's population. In the Alternative scenario, the State's population is expected to cross 160 million by 2050 contributing about 8.9% of the country's population. The CAGR of the population of Maharashtra during the projection period for the alternative scenario is estimated to be 1.03% and in the BAU was estimated to be 0.93% during 2001-2051.

Maharashtra is expected to be the second most urbanized State of India after Tamil Nadu with an urbanization of 62% in 2050. It is expected that growth in rural population would slow down and stabilize by the end of 2021, while urban population would increase to reach close to 100 million by the end of the analysis period of 2051. In the Alternative scenario, the rural population is expected to reach a level of 60 million and the urban population is estimated to surpass its rural counterpart and reach a mark of about 100 million. The rural population is expected to be stabilized by the end of the projection period while the urban population is estimated to soar up owing to the rapid pace of urbanization and industrial development that is taking place in the State already.

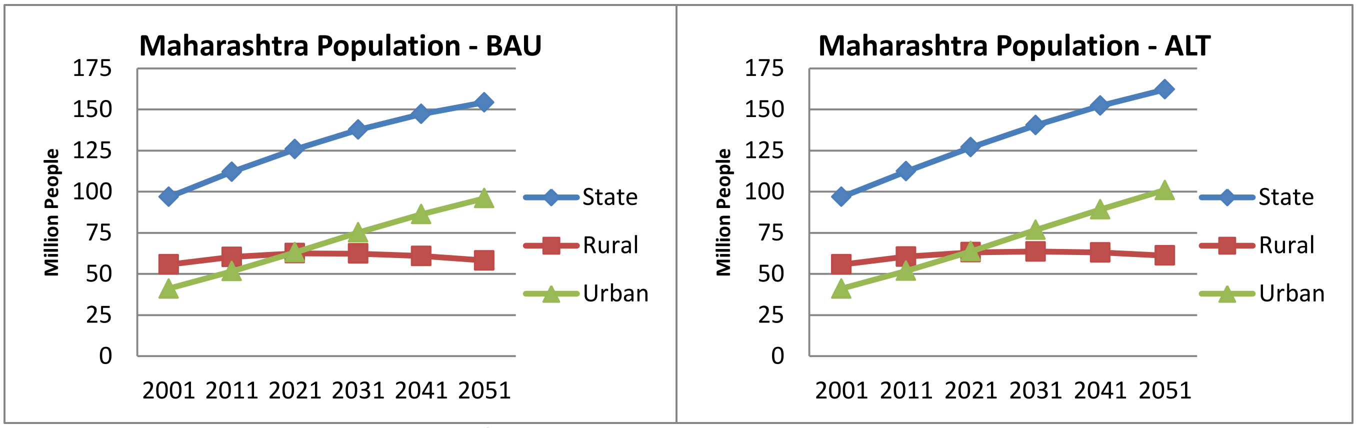


Figure 1: Projected total Population of the selected States under BAU Scenario and ALT scenarios (Source: PFI)

At a district level the results are much more heterogeneous. In a few districts like Bhandara, Gondia, Ratnagiri, Sindhudurg and Satara, total population is expected to decrease by the end of the projection period. This is mainly because these are agricultural districts and industrial development is limited compared to that of the other neighboring districts like Kohlapur, Nagpur, Pune and Thane that tend to draw population towards them in search of employment and livelihood.

The rural-urban distribution of population across districts varies significantly. Districts like Latur, Jalna, Jalgaon and Hingoli are expected to exhibit an increase in both rural and urban population such that rural population is greater than urban population in total magnitude terms. In districts like Aurangabad, Nashik and Raigarh, while both rural and urban population is increasing, urban population surpasses the rural population in terms of magnitude in the middle of the projection period. In Thane, Nagpur and Pune, rural population is expected to stabilize while urban population increases significantly towards the end of the projection period. This is attributed to the large scale industrialization and infrastructural development that is carried out in these states resulting in a huge volume of in-migration of people in the urban areas of these districts. In a few districts like Gandchiroli and Gondia, rural population is expected to increase while the urban population is expected to reach a stable level based on current trends.

5.2 GDP projections

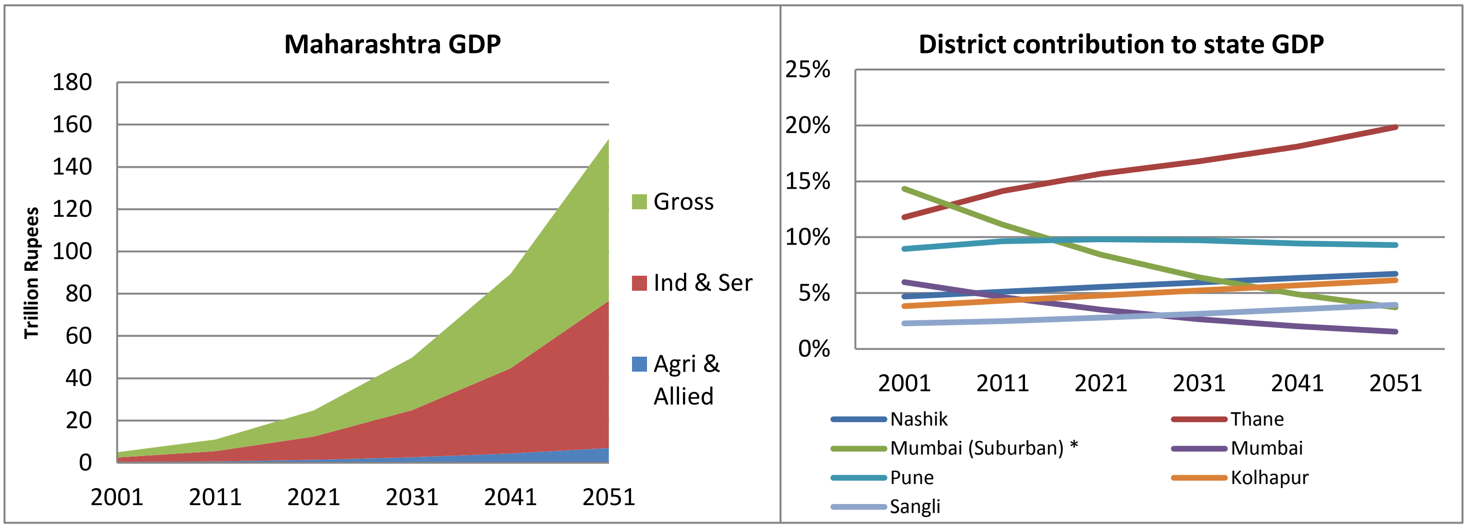
An analysis of the past GDP trends provides an understanding of the direction and level of development and helps in projecting likely growth in the near term. However, long term estimation of GDP is not only difficult but also associated with high degree of uncertainty. In the absence of consistent and long-term district level GDP estimates, TERI made its own projections of national GDP disaggregated across States and districts within a consistent framework[16].

The State of Maharashtra accounts for the highest contribution to the nation's GDP, accounting for 13.2% in 2008, and it is estimated that it would continue to remain the highest contributor

[16] Detailed methodology provided in Technical Report

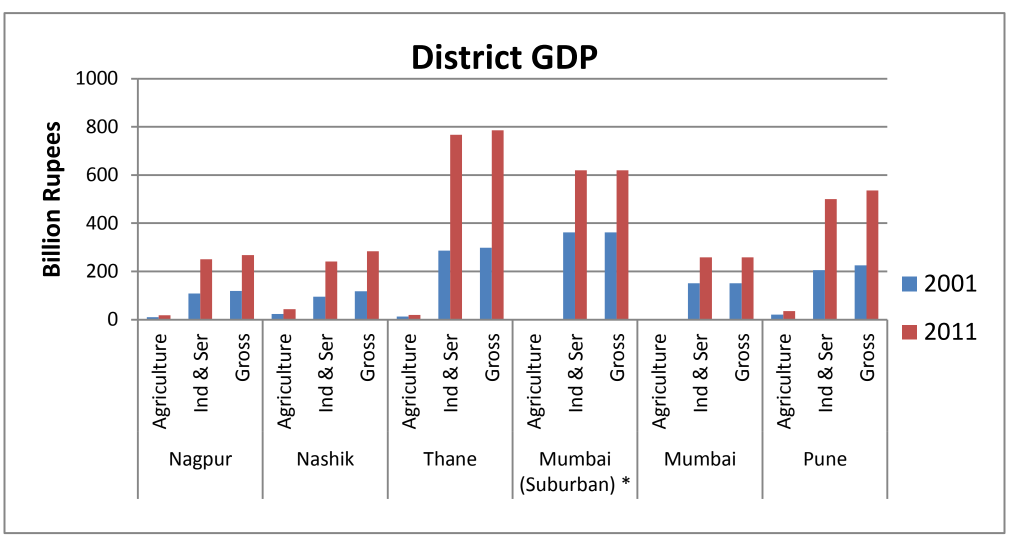
accounting for about 12.8% of national GDP in 2051. The overall economic growth rate of the State is expected to be at a CAGR of 7% till 2051, with agriculture and allied services growing at 5.9% while the industry and services growing at 7.1%. Accordingly, industry and services retain a higher contribution, while agriculture contributes to around 9.2% of the State's GDP in 2051.

Figure 2: Sectoral GDP of Maharashtra and contribution of major districts to State GDP in Maharashtra



In terms of contribution by individual districts Nagpur, Nashik, Thane, Mumbai and Pune continue to be the highest contributors. The proportional contribution by Mumbai is expected to decline as it reaches saturation. Instead the neighboring districts are expected to have a high contribution, particularly Thane. By 2051, Aurangabad is also expected to make a proportionally higher contribution and is expected to be close to Mumbai is terms of contribution. Some of the districts are graphed in Figure 3.

Figure 3: Change in sectoral GDP for major districts between 2001 and 2011



As is evident, the GDP of the important districts are expected to double over the decade. Again Mumbai is seen to undergo slightly slower growth due to saturation. Among the districts Thane is expected to be one of the faster growing districts growing at an average rate of 8.1% till 2051. Mumbai on the other hand is expected to grow at a slow pace of merely 4.1 % while Aurangabad is seen to grow rapidly at 7.6%.

Mumbai's agricultural sector contribution is expected to drastically reduce as land is expected to be acquired by the industry and services sectors. Figure 12.2 indicates the percentage contribution of some districts in Maharashtra. As is evident while Pune is almost stable, Kolhapur, Nashik and Sangli show slight gain in the percentage contribution to total GDP. However the biggest gain is shown by Thane at the expense of Mumbai and Mumbai (Suburban). Although this is a stark change it is not a surprise since Thane is geographically adjacent to Mumbai, and with severe space constraints in Mumbai Thane has started to develop rapidly and in the future could be expected to take over Mumbai as the prime economic hub of the State.

While in 2001 the top three districts, Thane, Mumbai (Suburban) and Pune contributed to around 35% of the State's GDP, in 2051 Mumbai (Suburban) gets replaced by Nashik as one of the three largest districts and along with Pune and Thane go on to contribute 36% of the State's GDP.

Despite data limitations and lack of details regarding various socio-economic parameters at the district level, the population and GDP disaggregation at the district level provides an idea about the variations in population growth and urbanization trends. Maharashtra is expected to stabilize its population growth rate and is expected to be the third most populated state of India by 2051. In terms of urbanization, it continues to have a high rate of urbanization.

6. Land use and land cover change projections for 2030s

6.1 Current status of land use and land cover (LULC)

As an important component of the VA study, TERI has used advanced satellite imaging analysis to identify 9 land use land cover classes in the region including 4 major phenological forest types. Table 1 gives the relevant area statistics of LULC categories mapped for years 1998, 2005 and 2012. Degraded forests are the regions having fragmented forest types of all kind and predominantly tropical moist and dry deciduous forests. The forest covers around 20.94% (for the year 2012) of the State's entire geographical area. The non-forest and land use classes include open land, agriculture, settlement and water bodies.

Table 1: Land use land cover area statistics for the year 1998, 2005 and 2012

Name	Area (sqkm)	Area (%)	Area (sqkm)	Area (%)	Area (sqkm)	Area (%)
Tropical Evergreen	872.05	0.28	872.05	0.28	872.05	0.28
Tropical Semi Evergreen	3147.83	1.02	2687.89	0.87	2208.63	0.72
Tropical Moist Deciduous	12582.13	4.09	11414.80	3.71	11414.80	3.71
Tropical Dry Deciduous	45774.19	14.88	38797.81	12.61	38756.42	12.59
Degraded Forest	13149.70	4.27	11081.80	3.60	11181.15	3.63
Open Land	16891.77	5.49	39097.69	12.71	45169.83	14.68
Agriculture	208647.36	67.81	193769.21	62.97	186306.21	60.55
Water Body	3555.34	1.16	3778.87	1.23	3801.87	1.24
Settlement	3092.64	1.01	6212.87	2.02	8002.04	2.60
	307713		307713		307713	

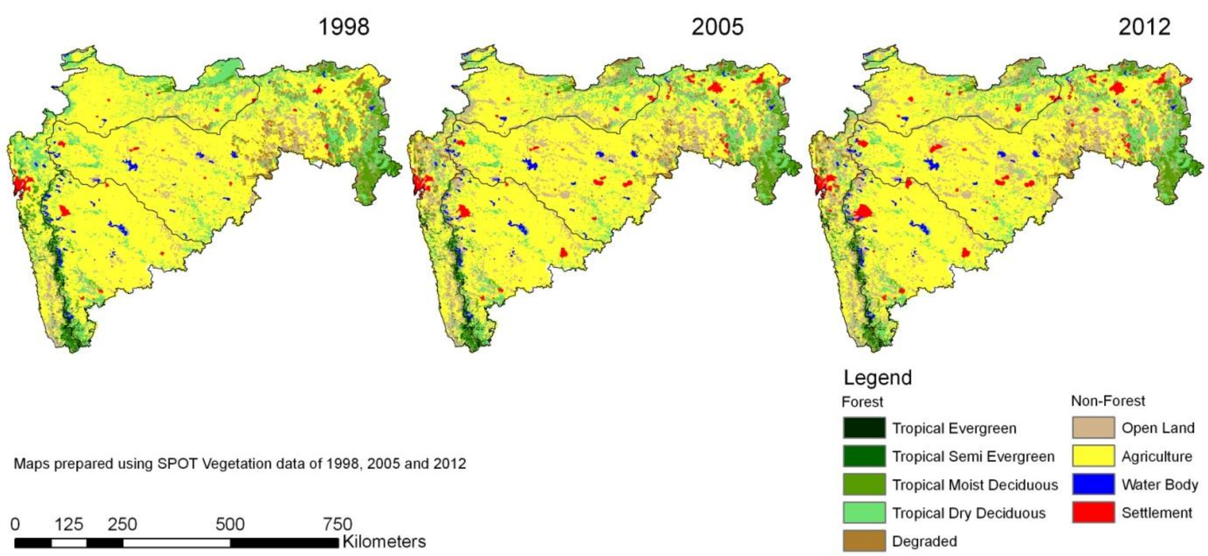


Figure 1: Land use land cover map (1998, 2005 and 2012)

6.2 Projected changes in LULC in 2030s

6.2.1 Methodology

In order to model land use and land cover change for Maharashtra, TERI has used a widely-used model, viz. Land Use Land Change Modeller (Markov Chain model) in IDRISI platform that combines GIS and remote sensing software. TERI has used remote sensing data from 1998, 2005, and 2012 in this model to analyze trends in land use land cover change.

Validation against remote sensing data shows that the model is very good at capturing ecological changes, but in the longer term, it has limitations when it comes to socio-economic drivers of land use land cover change.

Accordingly, the present study has utilized the model to project land use land cover change for the intermediate time slice of the 2030s. For this time slice, we have compared the model outputs with the observed trends in land use pattern in a number of spots, and there is a fair degree of confidence that the projected changes are consistent with past and ongoing trends. Based on the feedback received, we have also re-classified settlements as urban (such as those around Pune) and rural (such as those in Nandurbar or Gondia).

For the longer-term time slices of the 2050s and 2070s, the model has limitations in distinguishing between land use types that are driven by future socioeconomic factors. (For instance, the model projects future increases in settlements on the basis of parameters such as past trends in conversion of degraded and open areas to agriculture and settlements, distance from existing settlements, distance from major roads, and distance from natural drainage channels and topography, but the model outputs are not able to accurately classify agriculture and rural settlements.) This limitation has been taken into consideration by the study team in assessing the adaptation policy implications.

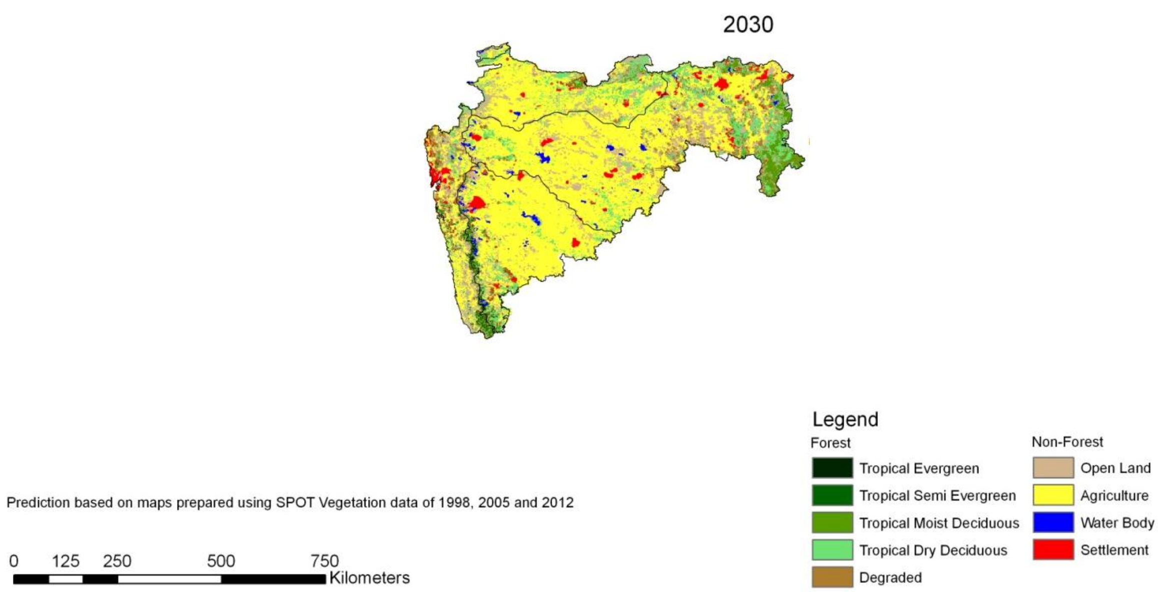
6.2.2 Results

Tropical evergreen forests have shown a very low rate of degradation in past decade and there is least probability (<0.05) of conversion of this into other classes. On the other hand, tropical semi-evergreen forests, tropical moist deciduous forests and tropical dry deciduous forests are consistently decreasing having high changes of getting converted into agriculture and degraded forest. The agricultural land area has decreased over the period and settlements and water bodies (reservoirs) have increased over the period at very high rate. Settlements might experience a very high rate of changes in the forthcoming century at the cost of agricultural areas and open land.

Table 2: Land use land cover area projections for the 2030s

Name	Area (sqkm)	Area (%)
Tropical Evergreen	872.05	0.28
Tropical Semi Evergreen	1416.62	0.46
Tropical Moist Deciduous	11414.80	3.71
Tropical Dry Deciduous	38756.42	12.59
Degraded Forest	11218.87	3.65
Open Land	45924.13	14.92
Agriculture	182266.10	59.23
Water Body	3801.87	1.24
Settlement	12042.16	3.91
	307713	

Figure 2: Land use land cover map for 2030s



7. Integrated Vulnerability Assessment for the State and 'Hotspots'

A large state like Maharashtra with a long coastline, varied geography and an economy closely tied to climate sensitive sectors like agriculture is likely to be highly vulnerable to impacts of changes in temperature, precipitation patterns, frequency and intensity of extreme events such as droughts, floods, cyclones, storm surges, heat wave etc. In order to initiate policy action to address the State's vulnerability to climate change it is essential to measure it, in order to understand the relative risks and where to direct action.

The following sections describe the development of a macro level vulnerability index (MLVI) for the state of Maharashtra using a multiple indicator based approach wherein the different indicators are aggregated to represent the IPCC three contributing factors to vulnerability (exposure, sensitivity, adaptive capacity). A composite index is then constructed by aggregating the above there factors. The MLVI is constructed on the basis of 19 major indicators representing exposure, adaptive capacity and sensitivity which have been selected on the basis of a literature review and taking into consideration the applicability of these variables for the context of Maharashtra.

7.1 Measuring vulnerability using indicator-based approach

Vulnerability is a dynamic phenomenon often in a continuous state of flux, with both the bio-physical and social processes that shape local conditions and the ability to cope being dynamic (O'Brien et al., 2004). Vulnerability of populations to climate change is multi-dimensional and it does not manifest due to climate alone but rather arises in the presence of multiple stressors. It is well acknowledged that it is not only the geographic location of the population, and the frequency and magnitude of the hazards, but also the social and economic condition of those at risk that combine to determine how people cope with and recover from changes in the environment (Adger, 2006; Cannon, 1994; Wisner et al.2004, Fussel, 2007). With an advance in vulnerability science there has been a shift from qualitative work centered on conceptual frameworks to quantitative or empirical measures of vulnerability. However, vulnerability is not easily reduced to a single metric and is not easily quantifiable.

To apply the concept of vulnerability in policy-driven assessments it is necessary to be able to measure it. It is difficult if not impossible to systematically identify which systems are most vulnerable and why without some criteria one system is said to be more or less vulnerable than another. However, defining a criteria for quantifying vulnerability has proven difficult, in part because vulnerability is often not a directly observable phenomenon (Downing et al., 2001). The most common method of quantifying vulnerability has been the use of indicators based approach, where indicators serve as proxies for the multi-dimensional issues associated with vulnerability (e.g. Moss et al., 2002; Kaly et al., 2002). Indicators are 'quantitative measures intended to represent a characteristic or a parameter of a system of interest using a single value'

(Cutter et al., 2006). The Organization for Economic Co-operation and Development (OECD, 2003) defines indicator as a value derived from parameters, which points to, provides information about, and describes the state of a phenomenon or environment of area, with a significance extending beyond that directly associated with a parameter values. On the most general level, the purpose of indicators is to describe the state of affairs of a complex system in simple terms (in Hinkel, 2011). Since indicators reduce complexity, they are, by their very nature, useful to communicate complex issues from science to policy or the general public. Hinkel (2011) highlighting the usability of indicators in decision making process notes that indicators are often particularly designed for policy making or monitoring the performance of policy measures and many policy documents, in fact, directly suggest the development of indicators. A prominent example is the Agenda 21 stating that ''indicators of sustainable development need to be developed to provide a solid basis for decision making''.

Indicators represent different facets of vulnerability and are often aggregated to generate a composite index of vulnerability. In several cases, indicator based approach is used for analyzing macro level vulnerability. However, as the factors of vulnerability are quite dynamic so the vulnerability scenario changes as we move down to lower administrative levels. During the past ten years, a number of indices related to vulnerability, sustainability, and quality of life have gained prominence in the literature. Among them are the Environmental Vulnerability Index (EVI), Environmental Sustainability Index, Human Development Index (HDI) and Human Well-being Index. Most of these indices like the HDI and EVI are examples of composite indices calculated by using a weighted average of the individual indicators.

Conceptualization of vulnerability for vulnerability assessment process

Most of the climate vulnerability assessments rely heavily on the working definition of IPCC (2007), wherein vulnerability is defined as 'the extent to which a natural or social system is susceptible to sustaining damage from climate change' and is a function of exposure, sensitivity and adaptive capacity. ***Adaptive capacity*** describes the ability of a system to adjust to actual or expected climate stresses, or to cope with the consequences. It is considered ''a function of wealth, technology, education, information, skills, infrastructure, access to resources, and stability and management capabilities''. **Sensitivity** refers to the degree to which a system will respond to a change in climate, either positively or negatively. ***Exposure*** relates to the degree of climate stress upon a particular unit of analysis; it may be represented as either long-term changes in climate conditions, or by changes in climate variability, including the magnitude and frequency of extreme events(IPCC, 2001) .

V = *f* (Exposure, Sensitivity, Adaptive Capacity)

In the above expression vulnerability is directly functional to exposure and sensitivity and inversely functional to adaptive capacity.

Index based approach to vulnerability assessment has become common for empirically quantifying vulnerability. These indices are built on indicators which represent the context of assessing the vulnerability. They facilitate comparison between the relative vulnerabilities at different scales of assessment (regions or administrative units). This inherently helps in policy formulation as well as for resource allocation and identifying adaptation interventions under the umbrella of larger development programmes (Eakin et al., 2008).For example, the Livelihood Vulnerability Index developed by Hahn et al (2009), uses several indicators to assess the impacts of climate change and variability among individuals residing in two districts in Mozambique. They use primary data gathered from household surveys in the study area based on the following components: socio-demographic profile, livelihood strategies, social networks, health, food, water, and natural disasters and climate variability. This index weights all indicators equally when assessing those factors that determine sensitivity and exposure to climate change impacts. Another innovative approach to assessing climate change variability employs the Dynamic International Vulnerability Assessment (DIVA) tool. Torresan et al (2008) employed this methodology to assess vulnerability to climate change and sea level rise along the coast of Venetia, Italy. The majority of indicators that are used are biophysical, like geomorphology, topography, and vegetation. Similarly a number of indices have been developed to assess climate vulnerability at the national level and facilitate comparison across countries. Moss et al. (2002) developed Vulnerability-Resilience Indicator Prototype (VRIP) index which assesses the ability of different groups to adapt and cope with climate change in 38 different countries. Climate Vulnerability Index (CVI), developed by Sullivan and Meigh (2005) has been constructed for Small Islands Developing nations (SIDs). Adger et al. (2004) have developed the Predictive Indicators of Vulnerability Index (PIV) which focuses on risk (outcome) as a function of both biophysical and social vulnerability.

A key difference amongst all the above mentioned indices has been the scale of assessment**,** methods used for selecting and aggregating indicators and display of results. All these often challenge the development of vulnerability indices and hence a general agreement on measuring vulnerability remains uncertain. However, there is considerable research and policy interest in developing these vulnerability indices as they can offer key insights for planning in the context of climate change.

7.2 Developing Macro-level Vulnerability Index for the state of Maharashtra

Indicator- based approach fundamentally assesses vulnerability to climate change in quantitative terms using individual indicators and aggregating them into an index to get overall vulnerability. The (1) first step in index development is the selecting the indicators which capture the key context specific vulnerabilities in terms of sensitivity, adaptive capacity and exposure to climate change. The next stage is (2) data collection which forms a significant step in indicator based approach. Besides data collection, the unit of analysis also forms an important aspect. This is followed by (3) data analysis and aggregation to (4) develop the vulnerability index. These stages are been explained as follows:

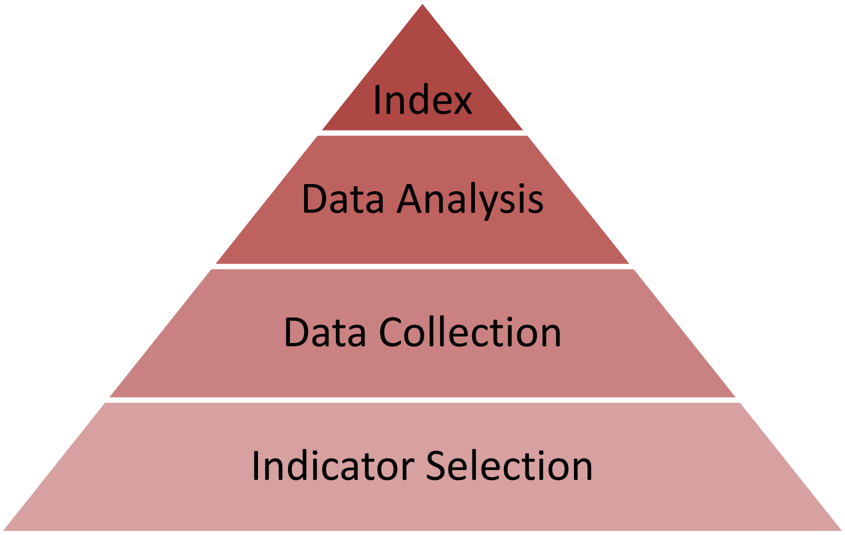


Figure 1: Index and Indicator development process

7.2.1 Indicator Selection

A vulnerability indicator can be defined as an operational representation of a characteristic or quality of a system able to provide information regarding the susceptibility, coping capacity and resilience of an element at risk to an impact albeit ill defined event (flood, landslide, drought) linked with a hazard of natural origin(Birkmann 2006). Indicator-development process needs to be related (explicitly or implicitly) to goals, or at least to a vision which serves as a basis for defining the *indicandum* (state or characteristic of interest). Queste and Lauwe stress the fact that indicators, from a practical point of view, should guide decision-making (knowledge for action). They argue that indicators should enable administration at different levels to integrate vulnerability reduction strategies into preventive planning. While Benson (2004) notes that the purpose of vulnerability assessment is to facilitate knowledge of understanding. In the context of the study the key objective of the vulnerability assessment process is identifying hotspots for priority setting that would further serve as background information leading to action. Setting priorities and background for action is listed by Birkmann (2005) as important criteria guiding the selection of vulnerability indicators. There are several methods for selection of indicators. . The choice of indicators going into an index is either data-driven (inductive) versus theory-driven (deductive) or a combination of both.This study employs a combination of both approaches wherein a thorough literature review has been done to arrive at a set of indicators which are specific to the vulnerabilities in the state of Maharashtra. This has been supported by a review of all the information available through major sources which includegovernment reports, documents and other published materials on relevant issues. Indicators representing changes observed in climatic variables are taken under *exposure* component. Climate sensitive sectors such as agriculture or natural resources such as water and forests are covered under *sensitivity*. Infrastructure development and socio –

economic developments have been represented under *adaptive capacity*. The indicators comprising the vulnerability for the state of Maharashtra are listed in figure 2.

7.2.2 Unit of Analysis

Before we initiate the process of vulnerability assessments it is important to have clarity on what is the unit of analysis. Unit of analysis helps us get a sense of scale at which the vulnerability assessment is carried. In this study, ***districts*** have been selected as the unit of analysis. This selection is guided by the fact that most development plans and interventions are designed at the district level. Further, data available for developmental indicators that are integral for the construction of the index is available at this scale. However Mumbai (which includes Mumbai and Mumbai sub-urban) has been excluded from this exercise due to non-availability of data for the indicators used in developing the index.

7.2.3 Data collection

The next step after the selection of indicators is the collection of data. If the method chosen for vulnerability assessment is primary data- based then the data is collected from the field through different methods, for example through the use of Participatory Rural Appraisal techniques. For macro level studies, such as that at District or State level, primarily secondary data is used. In case of secondary data based assessments, data is collected through various relevant government departments and data dissemination centers. Although there are certain limitations of secondary data based assessments such as authenticity of data, data inconsistency in some cases and data gaps still the assessments provides a useful means of assessment at the macro level. For the purpose of this study data was collected from secondary sources for the state of Maharashtra. Primarily the data used includes climate variables (on temperature, rainfall etc), socio-economic variables (literacy rate, demographic changes, access to basic amenities, infrastructure development, income etc.), natural resources (like forest cover, land-use change etc.).

7.2.4 Data Analysis and Index Development

Data analysis involves the processing of the data collected for each indicator which is followed by aggregating the different variables for index development. The methodology used for developing the index is as follows:

The macro level vulnerability index (MLVI) for the state of Maharashtra uses a multiple indicator based approach wherein the different indicators are aggregated to represent the IPCC three contributing factors to vulnerability (exposure, sensitivity, adaptive capacity). A composite index is then constructed by aggregating the above there factors. The MLVI is constructed on the basis of 19 major indicators representing *exposure, adaptive capacity and sensitivity* which have been selected on the basis of a literature review and taking into consideration the applicability of these variables for the context of Maharashtra. The vulnerability index developed is based on assessing the current vulnerability to the future climate. The study follows the approach adopted by O'Brien et al. (2004)[17] to asses vulnerability of Indian farmers to future climate change, wherein they assume that climate change exposure (i.e., ongoing and future exposure) will affect current sensitivity, either positively or negatively, and that farmers will respond to these changes in climate sensitivity if they have sufficient adaptive capacity. Similarly the macro –level vulnerability index developed for the state of Maharashtra is constructed by combining indices for adaptive capacity with sensitivity indices that take into account future exposure to climate change.

The ***exposure index*** consists of : warm nights index for 2030s, percentage change in rainfall from baseline (1960-1990) to 2030s, extreme wet days in 2030s, temperature humidity index for 2030s, difference in annual mean temperature at 2 meters above land for 2030s and districts exposed to sea level rise. The exposure index essentially takes the outputs of regionally downscaled general circulation models for the above variables and aggregates them into district wise index.

The ***adaptive capacity index*** is a combination of two sub indices: social development index (SDI) and infrastructure index. SDI is a reflection of the socio-economic status and level of development in the different districts of the state and includes road facilities, health care facilities, per capita income, literate population, number of farmers insured. While infrastructure index, includes villages' electrified, cooperative societies and banking facility available to the people.

The ***sensitivity index*** attempts to capture the sensitivity of human and ecological systems to climate change. The index is aggregation of percentage of wasteland area to total geographic area, marginal worker population to total worker population, contribution of primary sector to district domestic product, percentage of gross irrigated area to cropped area and percentage of state forest to total geographic area in the state.

Finally to represent the climate vulnerability in the state, macro-level vulnerability index was developed by aggregating the district-level index of adaptive capacity, sensitivity and exposure. The resulting macro-level climate vulnerability index represents *current* vulnerability to *future* climate change across districts in the state of Maharashtra. The MLVI uses a balanced weighted approach where each sub-indicator contributes equally to the overall index.

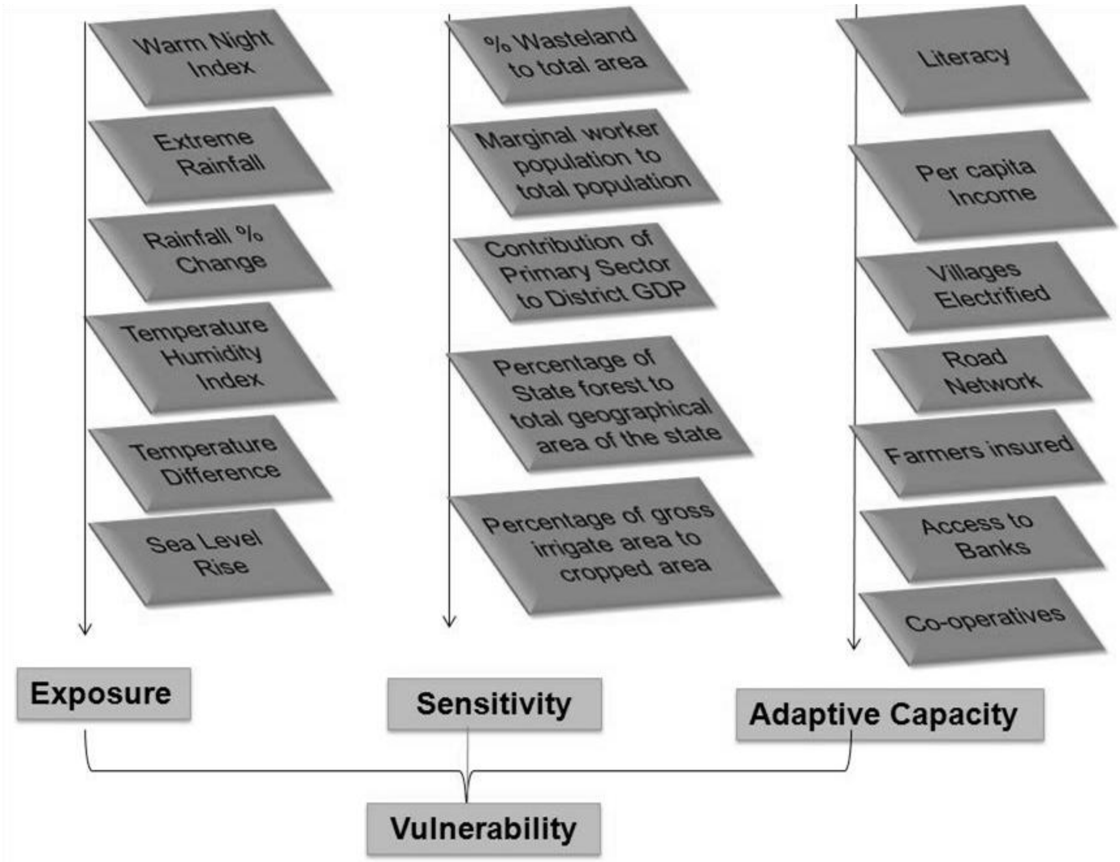


Figure 2: Indicators comprising the macro-level vulnerability index of Maharashtra

7.2.5 Index Calculation

The first step towards constructing an MLVI was normalizing each of the selected sub-indicators constituting the major indicators. Also because each of the sub-indicators was measured on a different scale, they were standardized as an index. The formula used for calculating the index, follows the basic approach developed by (Anand and Sen, 1994)[18] for the calculation of the human development index (HDI).

The following steps elaborate the calculation used:

Step 1: Calculate a dimension index for each of the indicators for a district (D1) by using the equation:

$$\text{Index } X_d = X_d - X_{min} / X_{max} - X_{min}$$

Where:

X_d: actual value for district d

X_{max}: Maximum value

[18] Anand, S., and Amartya Sen, 1994.Human Development Index: Methodology and Measurement, Occasional Paper 12, United Nations Development Programme, Human Development Report Office, New York.

X_{min}: Minimum Value

Step 2: After each of the sub indicators were standardized, they were averaged using the following equation to calculate the value for the major indicator:

$$Y_d = \Sigma \text{Index } X_d / n$$

Where:

Y_d: is one of the major indicators for district d

Index X_d: represents the sub indicators in each major indicator

n: is the number of sub-indicators in each major indicator

Step 3: After the index values for all the major indicators were calculated for all the districts, the major components were combined according to the categorization scheme given by the IPCC (see above). The following equation was used to calculate the indices for the all 3 contributing factors of vulnerability as given by the IPCC vulnerability (exposure, sensitivity, adaptive capacity)

$$ICF_d = \Sigma W_i Y_d / \Sigma W_i$$

Where:

ICF_d: is the IPCC defined contributing factor to vulnerability (exposure, sensitivity, adaptive capacity)

W_i: is the weight of major indicator which are determined by the number of sub-components that make up each major component and are included to ensure that all sub-components contribute equally to the overall MLVI

Y_d: Are the major indicators for district d indexed by i

Step4: Once indices for exposure, sensitivity and adaptive capacity were calculated, they were combined to calculate the Macro level Vulnerability Index for each of the districts in Maharashtra, using the following equation:

$$MLVI = (E_d * S_d) -$$

Where:

E_d: is the calculated exposure score for district

A_d: is the calculated adaptive capacity score for district d

S_d: is the calculated sensitivity score for district d

The Macro-level vulnerability index for the state has been scaled from -1(least vulnerable) to1 (most vulnerable).

7.3 District-wise vulnerability index and ranking

Table 1 presents the district wise vulnerability index of the state along with the index measures of the contributory factors – climate exposure, adaptive capacity, and sensitivity. The index ranges from lowest value of -0.45 (Satara) to the highest value of 0.02 (Nandurbar). Accordingly, these are the two districts are identified to be the least vulnerable and most vulnerable, respectively. It is important to reiterate at this stage that the results presented in this study refer to *current vulnerability to the future climate*. For the contributory factors 'exposure' and 'sensitivity', ranking of districts from 1 to 33 follows the descending order of corresponding index measures, whereas for 'adaptive capacity', it is the reverse. Thus the district of Jalgaon is found to be the most exposed to climatic risks in the 2030s and Sangli the least. While Nandurbar has the least adaptive capacity and Sindhudurg the highest, the districts of Gadchiroli and Aurangabad are, respectively, the most and least sensitive to climatic risks.

Table 1: District wise ranks for macro level vulnerability index and contributing factors

District Name	Exposure	Sensitivity	Adaptive Capacity	Vulnerability Index
Ahmedanagar	20	26	9	20
Akola	4	6	11	21
Amravati	13	8	20	16
Aurangabad	12	1	13	27
Bhandara	19	30	10	11
Bid	24	16	22	14
Buldhana	8	17	32	3
Chandrapur	23	28	6	22
Dhule	2	19	29	2
Gadchiroli	27	33	14	10
Gondia	18	31	15	8
Hingoli	15	21	31	5
Jalgaon	1	13	26	4
Jalna	17	18	30	7
Kolhapur	32	20	8	30
Latur	28	2	17	24
Nagpur	21	9	12	23
Nanded	25	5	28	15
Nandurbar	5	29	33	1
Nashik	6	24	25	6
Osmanabad	29	3	27	17
Parbhani	22	10	18	18
Pune	26	25	7	28
Raigad	7	14	5	26
Ratnagiri	11	12	2	32
Sangli	33	23	16	25
Satara	31	27	3	33

Sindhudurg	16	32	1	31
Solapur	30	11	23	19
Thane	3	4	21	12
Wardha	14	7	4	29
Washim	9	22	24	9
Yavatmal	10	15	19	13

The maps below (Figures 3 to 6) represent the exposure, sensitivity, adaptive capacity and overall vulnerability of different districts of Maharashtra. The maps have been developed with respect to 7 classes ranging from very low to very high vulnerability.

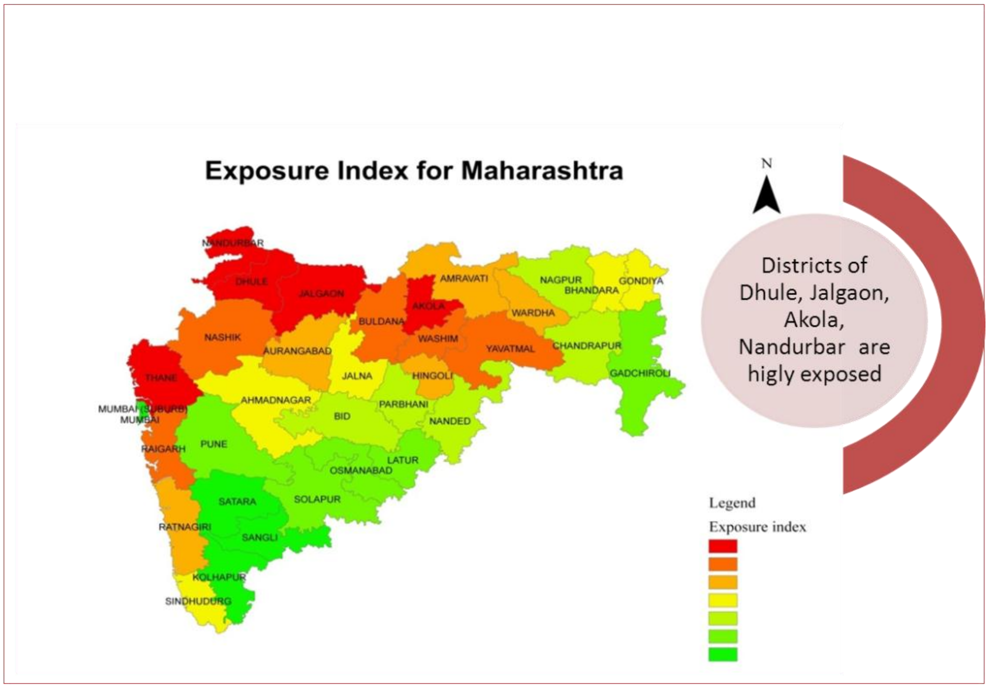


Figure 3: Map for Exposure Index for different districts of Maharashtra

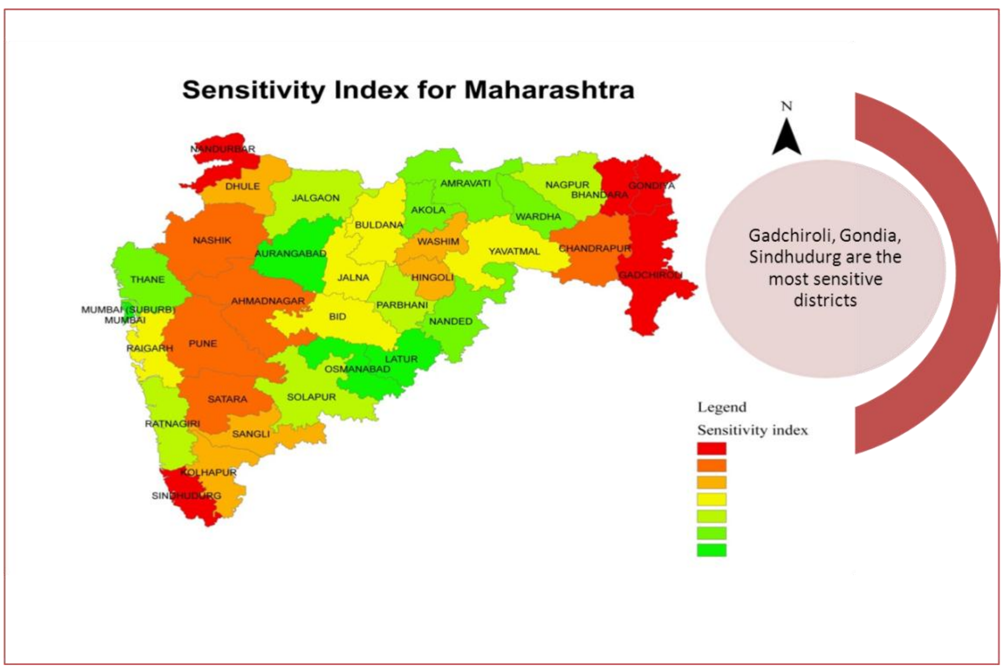


Figure 4: Map for Sensitivity Index for different districts of Maharashtra

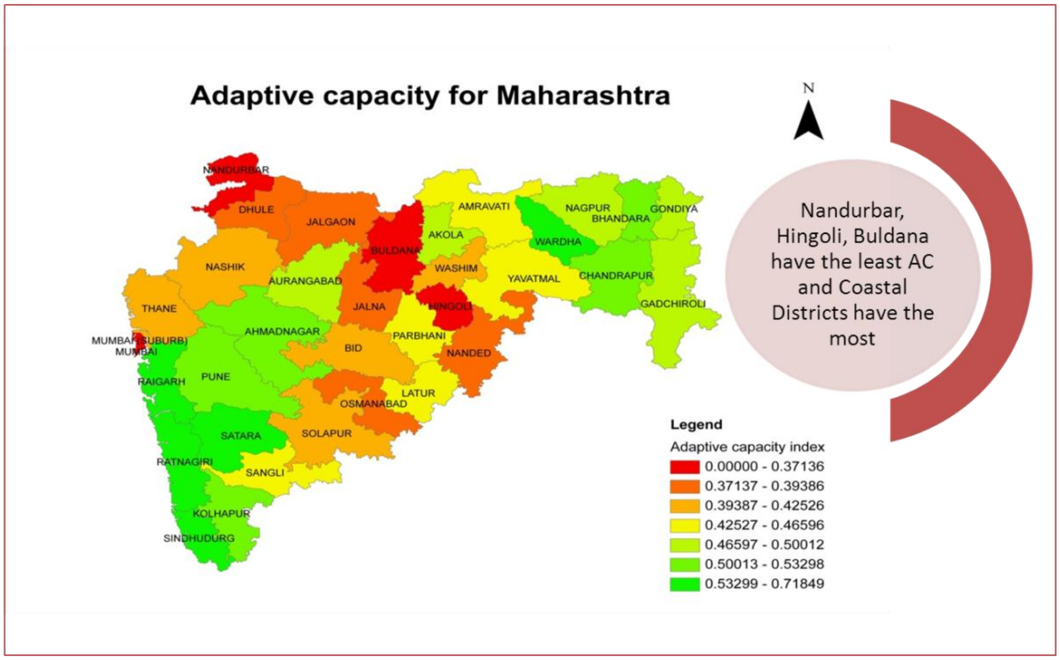


Figure 5: Map for Adaptive Capacity Index for different districts of Maharashtra

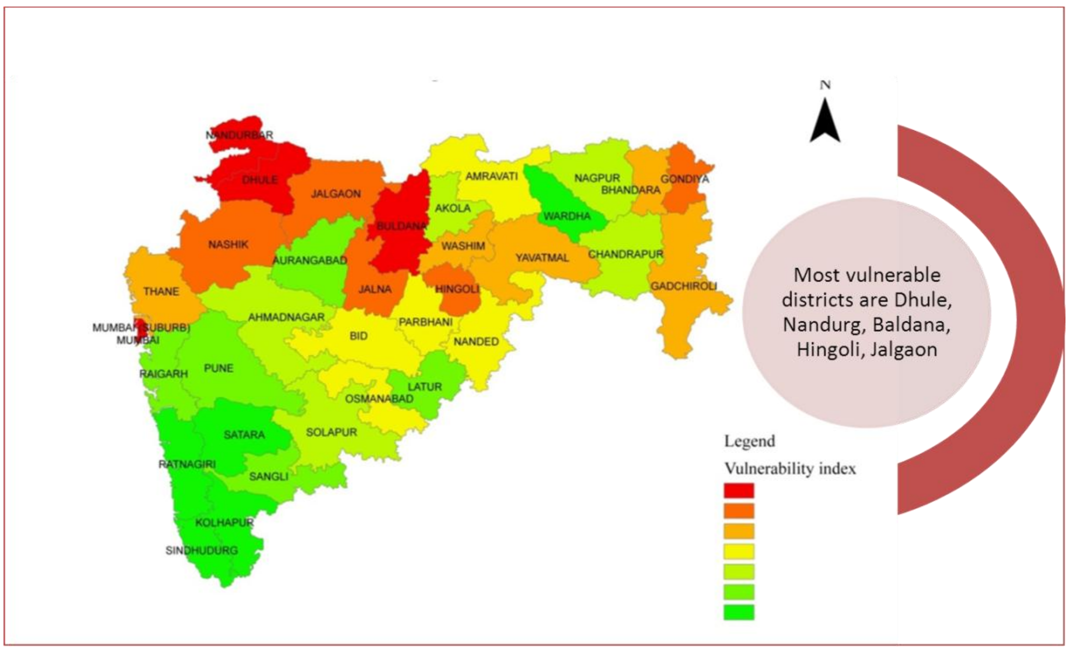


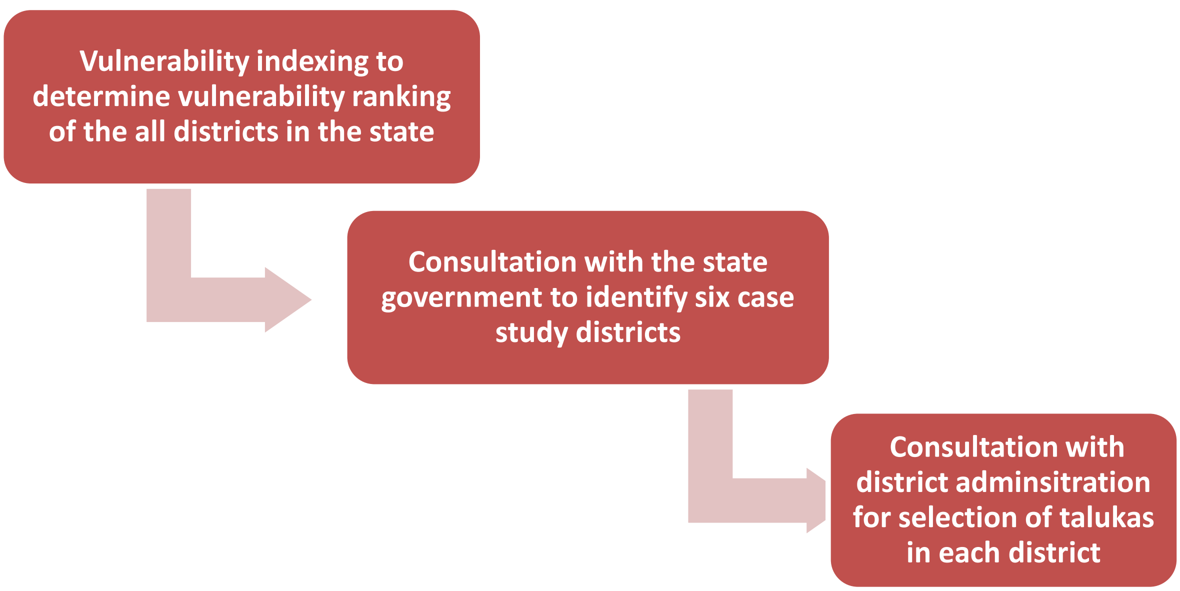
Figure 6: Map for Macro-level Vulnerability Index for different districts of Maharashtra

7.4 Approach for Case Study Site Selection

One of the primary objectives for developing the macro level vulnerability index for the state was to identify six *hotspots* or potential case study sites for carrying out participatory field based assessments. Figure 7 outlines the approach adopted for selecting the case study sites:

1. **Vulnerability ranking of all districts**: in order to select the most vulnerable districts for doing participatory field based assessment, vulnerability ranking of the each district was done using the marco-level vulnerability index.
2. **Consultation with the state government and selection of the case study districts:** The macro level vulnerability index was presented to the state government[19] and after consultation with the state administration it was agreed that the most vulnerable district in each division would be selected for further detailed assessments. The district selected included: Buldhana (Amaravati division), Solapur (Pune division), Gondia (Nagpur division), Nandurbar (Nashik division), Thane (Konkan division), Hingoli (Aurangabad division).
3. **Participatory selection of case study sites**: Thereafter consultations were undertaken with the district administration and two *talukas* in each district were selected for carrying out multi- stakeholder consultations.

Figure 7: Approach for selection of Case Study Sites



[19] Presentation before the state government on 7/08/2012

Table 2: Selected case study districts and talukas:

Division	District	Talukas
Amravati Division	Buldhana District	Lonar taluka Khamgaon taluka
Pune Division	Solapur District	Sangola taluka Pandharpur taluka
Nagpur Divison	Gondia District	Amgaon taluka Deori taluka
Aurangabad Division	Hingoli District	Sengaon taluka Kalamnuri taluka
Nashik Division	Nandurbar District	Dhadgaon taluka Shahada taluka
Konkan Division	Thane District	Tanke taluka wada taluka

7.5 Additional case study of Mumbai

Though Mumbai was excluded from index development, however given its prime location and high vulnerability to sea level rise, an analysis of different variables constituting the exposure to climate change was carried out. Table 3 presents the different values for each of the variables for the districts of Mumbai and Mumbai sub-urban and compares it with maximum and minimum values amongst all districts. The red colour essentially represents those values which coincide with either maximum or minimum values thereby highlighting that either of the two districts or both have extreme values for the climate variable in question. It can be inferred that amongst the four out of five variables considered, the districts of Mumbai and Mumbai sub-urban give either maximum or minimum values, thus representing high exposure of these districts to climate change. For example Mumbai shows the maximum value for Heat Index (felt air temperature), which indicates that maximum discomfort from the felt temperature will be experienced by the people of Mumbai.

Table 3: Exposure indicators for Mumbai and Mumbai Suburban

EXPOSURE INDICATORS (In The 2030s)	MUMBAI	MUMBAI (Suburban)	MAXIMUM	MINIMUM
Extreme rainfall	12.95	**10.95***	28.32	**10.95**
Heat index	**66.2**	57.382	**66.21**	44.7795
Rainfall percentage change	18.727	20.565	36.77	10.777

EXPOSURE INDICATORS (In The 2030s)	MUMBAI	MUMBAI (Suburban)	MAXIMUM	MINIMUM
Difference in annual average temperature	**1.01**	1.2	1.354	1.008
Warm nights index	**80.56**	65.758	**80.56**	**48.852**

8. Adaptation framework and priority setting

Climate change projections for Maharashtra indicate that average temperature and average rainfall will increase during the 21st century. The projected increase in the average quantity of rainfall, however, is expected to be accompanied by greater variability in the distribution of rainfall. The number of extreme rainfall days is projected to increase, but rainfall may be concentrated in fewer days interspersed with dry spells. A once-in-20 years extreme wet day is likely to occur more frequently by the end of this century, but projections range from once in 4 years to once in 15 years (IPCC SREX projections for South Asia). Hence the implications of climate change for Maharashtra are not just higher average temperature and rainfall, but also greater variability and uncertainty about the distribution of rainfall.

The adaptation framework for the Maharashtra State Action Plan on Climate Change takes cognizance of the uncertainty related to future climate, which will form the backdrop for policymaking in key climate-sensitive sectors. For instance, decisions regarding dam storage capacity, bridge height, crop cultivars, and coastal development, all need to take into account the range of climate change scenarios.

Further, climate change adaptation strategies need to be formulated in the presence of a water-energy nexus, which affects agriculture and food security on the one hand and industrial growth on the other. In the coming decades, more energy needs to be provided to meet basic human needs and also to facilitate industrial growth. Similarly, more water needs to be provided for irrigation, for industry, and for the drinking water needs of rural and urban populations. However, the extraction, treatment, and transport of clean water require energy, while the generation of power requires water. Climate change will increase the stress on already scarce resources (e.g. temperature rise will increase evaporation losses, sea level rise will lead to salinization of coastal aquifers), and add uncertainty to decision making (e.g., erratic rainfall and unreliable reservoir levels will affect the performance and efficiency of thermal, nuclear, and hydroelectric power plants). Acknowledging the water-energy nexus in the context of climate change is essential to develop effective adaptation strategies. Also, developmental policies that indirectly influence the demand for water and energy (e.g. agriculture pricing policies that encourage the adoption of water-intensive crops) will need to be reoriented to avoid maladaptive responses to climate change.

Moreover, the impacts of climate change on key sectors and ecosystems will adversely affect livelihoods – farming, livestock rearing, fishing, forest-based livelihoods, tourism, etc. Climate stresses and disasters threaten the viability of traditional livelihoods, exacerbating rural-urban migration, and heightening competition and conflict over dwindling resources. These, in turn, will hinder the attainment of desired developmental goals. Consequently, there is a strong need to develop long-term strategies to make livelihoods more resilient.

With this framework, the Maharashtra State Action Plan on Climate Change proposes a range of long-term adaptive strategies that combine supply side and demand side measures, market-based and regulatory instruments, institutional strengthening and knowledge management. There is a need to augment the capacity of existing infrastructure to deal with a range of climate change scenarios. This needs to be combined with measures to improve the efficiency of resource utilization. Monitoring of climate risks and establishment of effective early warning systems need to be complemented with risk diversification mechanisms including insurance and safety nets.

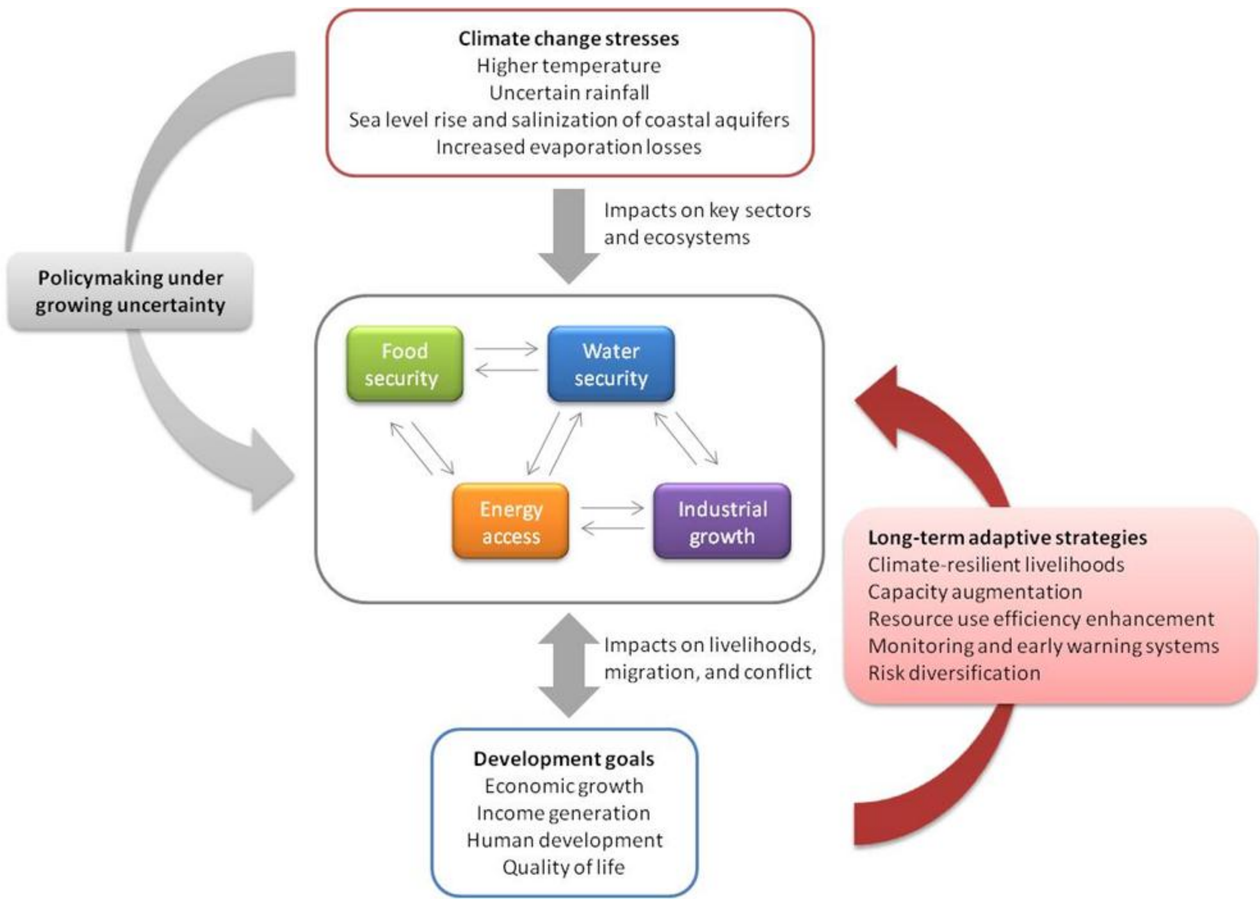


Figure 1: The MSAAPCC adaptation framework

Effective adaptation has to be need-based and context-specific. Criteria for choosing measures and prioritizing options may include the net economic benefits, the timing of benefits, distribution of benefits, net environmental impact, compatibility with existing government policies and programs, consistency with development objectives, implementation capacity, spillover effects, and social, economic and technical barriers. Once the adaptation strategy is evaluated on suitable criteria, the measure or the combination of measures that yield the greatest net benefit should be chosen as a priority for implementation. In identifying strategies for the MSAAPCC, the following four choice criteria have been applied to individual actions:

- **Relevance** of the proposed action to the long term goal of building resilience and/or addressing future vulnerability

- **Consistency** of the proposed action with current development priorities of the State and policy goals
- **Feasibility** of the proposed action in terms of cost effectiveness and social acceptance, (which brings in implicitly the political dimension as well)
- **Capability** at the institutional level to implement the proposed action.

9. Water resources in Maharashtra: climate change impacts and adaptation

9.1 Water resources in Maharashtra

9.1.1 Water resources potential: surface water and ground water

The estimated average annual availability of water resources in Maharashtra consists of 164 km^3 of surface water and 20.5 km^3 of subsurface water (http://www.mwrra.org). Out of the 5 river basin systems (Table 1), only 55% of the dependable yield is available in the four river basins (Krishna, Godavari, Tapi and Narmada) east of the Western Ghats. These four river basins comprise 92% of the cultivable land and more than 60% of the population in rural areas. An approximate 49% of the area of these four river basins consisting 43% of the population is already considered as deficit or highly deficit in water availability.

About 45% of the State's water resources are from west-flowing rivers which are mainly monsoon specific rivers emanating from the Ghats and draining into the Arabian Sea. However, this water cannot be fully utilized as the average altitude west of the Ghats (Konkan) is 60 metres above sea level and the average height of the Ghats is more than 600 metres above sea level[20].

Table 1: River basins and their water statistics

S. No	Name of Basin	Geographical a rea (Mha) / Percent of Area w.r. to Maharashtra	Culturable area (Mha)	Annual Average Availabil ity (Mm3)	75% Dependable yield (Mm3) / Percentage with respect to state	Permissible use as per Tribunal award / committee report (Mm3)
1	Godawari	15.43/49.5	11.25	50880	37300/28.35	34185
2	Tapi	5.12/16.7	3.73	9118	6977/5.30	5415
3	Narmada	0.16/0.5	0.06	580	315/0.24	308
4	Krishna	7.01/22.6	5.63	34032	28371/21.56	16818
5	West Flowing	3.16 /10.7	1.86	69210	58599/44.54	69210
	Maharashtra	30.80/100.0	22.53	163820	131562 /100	125936

Source: Maharashtra Water Resources Regulatory Authority (http://www.mwrra.org)

[20] (http://www.mwrra.org)

In the State, 90% of rural population is using groundwater resources. In agriculture sector, groundwater utilization is 85%. Some 10% of the ground water is utilized for industrial purpose and only 5% is used up for drinking. In large parts of western and central Maharashtra, where groundwater abstraction for sugarcane cultivation has reached unsustainable levels, groundwater resources are fast getting depleted. The most important aquifers in Maharashtra are the Deccan basalts, where groundwater occurs within the shallow weathered and fractured zones extending to depths of 15-20 meters. The average water table depths in the shallow aquifer range from 5 to 10 meters below ground level during the post-monsoon period and from 15 to 20 meters below ground level during the pre-monsoon period. The behaviour of the aquifer during drought conditions depends on a number of site-specific factors, such as the intensity of drought, extent of groundwater abstraction, storm pattern and location of the village in the watershed.

Table 2: Groundwater resources of Maharashtra[21]

	1989 Ground Water Estimation	1995 Ground Water Estimation	2000 G.E.C-97
Total Watershed Area	1505	1505	1505
Total ground water extraction (in lakhs)	11.51	12.63	13.33
Yearly refilling (in lakhs)	29.96	31.54	30.89
*SC/C/OE	34/75	26/87	277/72 /154

*SC- Semi Critical / C- Critical / OE- Over Critical.

9.1.2 Floods and droughts

Maharashtra is prone to drought and floods. Out of the total geographical area of Maharashtra, 40% of the area is drought prone and 7% is flood prone. While low rainfall areas of the State are under the constant risk of droughts, high rainfall zones of eastern and western Maharashtra are prone to flash floods. Many areas of the State have faced droughts for consecutive years, which damaged agriculture and caused water shortage in more than 20,000 villages. In July 2005, about 900 people died in the Konkan region due to heavy rainfall of about 37 inches.

Drought-affected districts in the State get annual rainfall in the range between 600 to 750 mm through the south-west monsoon, almost all of which is received between June to October. About 90 per cent of the land in the State has basaltic rock, which is nonporous and prevents rainwater percolation into the ground and thus makes the area drought prone. Around 12% of the population lives in drought prone areas and 60% of the cultivated area lies predominantly in drought-affected districts (Ahmednagar, Solapur, Nashik, Pune, Sangli, Satara, Aurangabad, Beed, Osmanabad, Dhule, Jalgaon, and Buldhana). Out of 100 talukas in the state, 45 have been identified as being drought prone, according to the Central Water Commission statistics (CWC, 2005). Once in 5 years, deficient rainfall is reported. Severe drought conditions occur once every

[21] (Groundwater Surveys and Development Agency, GoM)

8-9 years. Maharashtra experienced severe and successive years of drought in 1970-1974 and 2000-2004 (World Bank 2008). Due to regular drought frequency, low levels of irrigation coverage, literacy, and infrastructure development and poor coping & adaptive capacity, this region is highly vulnerable to impacts of climate change.

In Maharashtra, floods mainly result from damage to the dam embankments, release of excessive water from dams, improper storm-water drainage systems and unplanned urbanization. The rivers, which cause flood in the State, are the Tapi, Wardha and occasionally the Pen-Ganga. The eastern parts of the State are prone to floods. More than two lakh hectares of land in Maharashtra is prone to floods and Patur taluka in Akola district has the largest flood prone area in the State. Nanded and Nashik are frequently affected by floods in the monsoons. Chandori, Saikheda and Niphad are the three major flood-prone areas in Nashik district.

9.1.3 Climatic and non-climatic risks to water resources in the State

The Marathwada and Western Maharashtra regions are dry and drought-prone, while the Konkan and Vidarbha regions face rainfall variability (Table 3). Rainfall data from the period 1901-2003 shows that the share of monsoon rain falling in July has been decreasing, while August rainfall has been increasing (Guhathakurta and Rajeevan 2006). Moreover, there has been an increase in the contribution to extreme rainfall events to monsoon rainfall, especially during the first half of the season (June and July). While the frequency of extreme rainfall events has been increasing over the west coast, the frequency of low intensity rainfall events has been decreasing (Sinha Ray and Srivastava 2000). These trends indicate that Maharashtra could face an increase in rainfall variability, including droughts and dry spells, as well as increased likelihood of flooding. These observations also have important implications for groundwater recharge, since heavy intensity rainfall is lost as runoff while low intensity rainfall, which contributes to groundwater recharge, decreases in frequency.

Table 3. Summary of regional rainfall patterns and key climate vulnerabilities

Region	Divisions	Districts	Normal annual rainfall (mm)	Key vulnerabilities
Vidarbha	Amravati Nagpur	Amravati, Akola, Buldhana, Washim, Yavatmal Nagpur, Bhandara, Chandrapur, Gadchiroli, Gondia, Wardha	1104.6	Long dry spells, Recent increase in rainfall variability and decrease in amount, Salinity problem in Amravati, Akola, and Buldhana districts
Marathwada	Aurangabad	Aurangabad, Beed, Hingoli, Jalna, Latur, Naded, Parbhani,	840.4	Drought-prone, Low forest cover, Low irrigation availability

		Usmanabad		
Western Maharashtra	Nashik Pune	Nashik, Ahmedanagar, Dhule, Jagaon, Nandurbar Pune, Kolhapur, Sangli, Satara, Solapur	850.5	Drought-prone, Water-intensive cultivation, Soil erosion,
Konkan	Konkan	Mumbai City, Mumbai Suburban, Raigadh, Ratnagiri, Sindhudurg, Thane	2978.6	High intensity rainfall, Coastal salinity, Severe soil erosion

Source of rainfall data: India Meteorological Department

Rural Maharashtra is heavily reliant on ground water – it provides more than 70% of irrigation and 90% of drinking water for the State's rural population (CGWB 2004). While the average stage of groundwater development (i.e. ratio of extraction to availability) for Maharashtra is 48%, it exceeds 70% for the districts of Amravati, Sangli, Ahmednagar, Latur, Sindhudurg, and Pune, without even including the groundwater extraction by irrigation borewells (CGWB 2004). The areas with high degree of extraction have low rainfall but high share of water-intensive crops and deterioration of groundwater quality. Of the State's 35 districts, 29 have nitrate levels that are more than double the permitted limit.

Further, urban demand for water will pose an additional stress – Maharashtra already has six million-plus population cities, and is projected to become more than 60% urbanized by the 2050s.

Poor rainfall has affected all the irrigation projects in the drought affected regions of the State. The situation has become extremely difficult for the people who are dependent upon agriculture for their livelihood. The live storage in all the dams has been going down since 2000 in three divisions viz. Nashik, Pune and Aurangabad. In Pune and Aurangabad divisions, the total water available in reservoirs has depleted substantially. Not only has the low level of water storage reduced the water for irrigation and impacted the cultivation; it has a major impact on the availability of drinking water in these districts (Source: EIC).

9.1.4 Potential impacts of future climate change on water resources in Maharashtra

According to one assessment (Gosain et al., 2006), River Tapi is projected to experience constant water scarcities, Rivers Narmada and Krishna are likely to experience seasonal or regular water stressed conditions, and River Godavari is projected to experience water shortages in few locations. While rivers Tapi and Narmada irrigate most of North Maharashtra, Krishna and Godavari irrigate most of the central and eastern Maharashtra.

The World Bank (2008) study using the Integrated Modeling System (IMS) finds that the following changes may occur across the Godavari basin:

- An increase in precipitation of about 36% (to approximately 840 mm) in the A2 scenario and 24% (to about 770 mm) in the B2 scenario.
- An increase in annual maximum temperatures, on average of 3.8°C in A2 and 2.4°C in B2.
- Rainfall is found to become more variable but the variation will be very similar in B2 compared to A2; the higher rainfall is expected to increase runoff by 12.5% in B2 and by 13.5% in A2.

The frequency of droughts is projected to increase in future through changes in the hydrological cycle viz. precipitation, evapo-transpiration (ET), soil moisture etc. ET being the major component of hydrological cycle will affect crop water requirement, future planning & management of water resources. A study on sensitivity of ET to global warming for arid regions, has projected an increase of 14.8% in total ET demand with increase in temperature. It is also concluded that marginal increase in ET demand due to global warming would have a larger impact on the resource-poor, fragile arid zone ecosystem that constitutes a bulk of Maharashtra.

Spatial and temporal changes in temperature and precipitation may modify the surface hydraulic boundary conditions and ultimately cause a shift in the water balance of an aquifer. Variation in duration, amount and intensity of precipitation and ET will increase or decrease recharge rates. Moreover, land cover changes may increase or decrease recharge.

Rising sea levels will allow saltwater to penetrate farther inland and upstream in low lying river deltas. Higher salinity impairs surface and groundwater supplies, damaging urban water supplies, ecosystems, and coastal farmland.
Increase in flood frequencies may affect groundwater quality of aquifers. Increased flooding could increase the flushing of urban and agriculture waste into groundwater systems, especially into unconfined aquifer, and further deteriorate groundwater quality.

9.2 Impact of climate change on surface runoff in Maharashtra

9.2.1 Modelling methodology

TERI has carried out a model-based assessment of the spatial distribution of mean surface runoff for Maharashtra under projected climate change scenarios (2030s, 2050s and 2070s). In this study, Soil Conservation Service (SCS) method developed by United States Department of Agriculture (USDA, 1972) is used to compute surface runoff in the state of Maharashtra. SCS method is a versatile method and widely used procedure to estimate volume of direct surface runoff and also relatively easy to use with minimum data requirements (Chatterjee et al., 2001; Bhuyan et al., 2003; Elhakeem and Panicolaou., 2009). The model takes into account various properties of the watershed such as soil characteristics (texture, effective depth, infiltration rate, permeability etc.), land use, rainfall (antecedent soil moisture condition) and basin coefficients.

Basin coefficient, also known as runoff curve number (CN), represents the runoff potential of a particular land cover soil complex.

9.2.1.1 Data

Data used to perform surface runoff modelling for Maharashtra state include predicted rainfall data as provided by TERI climate model for baseline, 2030s, 2050s and 2070s. Percentage of clay and soil texture are derived from Harmonized World Soil Database (HWSD) to prepare Hydrological soil Group (HSG). Four types of soil texture found in Maharashtra state are – Sandy Loam, Sandy Clay Loam, Loam and Clay. Land Use Land Cover (LULC) used in this study is derived from SPOT Vegetation data.

9.2.1.2 Methodology

Computation of surface runoff requires several steps to be taken. Firstly the Hydrological Soil Groups are prepared on the basis of percentage of clay and soil texture for the soils of Maharashtra and is classified into four types viz. A, B, C and D. SPOT data is used to prepare LULC maps.

Further, LULC and HSG maps are combined to generate Hydrological Soil Cover Complex (HSCC). On the basis of various combinations of LULC and HSG, 20 HSCC units are made for Maharashtra state.

On the basis of established curve numbers for different combinations of HSCC, a base CN map is prepared for AMC-II (Antecedent Moisture Condition) for the rainfall events of the monsoon season viz. June, July, August and September months. AMC is an indicator of watershed wetness and availability of soil moisture storage prior to a storm. SCS has developed criteria for adjusting Curve Number (CN) according to AMC condition. The criteria are based on the total rainfall accumulated in a five day period prior to a storm event. Three levels of AMC are, AMC-I for dry, AMC II for normal and AMC-III for wet conditions.

Table 4. Classification of antecedent moisture conditions

AMC	**Total 5-days Antecedent Rainfall (mm)**	
	Dormant Season	Growing Season
I	<12.7	<35.6
II	12.7-27.9	35.6-53.3
III	>27.9	>53.3

In our assessment, we have chosen the extreme events for all the four months of the monsoon season. For each month, six to eight events are selected on basis of maximum, minimum, mean and total amount of rainfall. On the basis of total accumulation in the preceding 5-days of these selected events, AMC condition is assigned. Most the events fall in the category of AMC-III condition with very few occurring in AMC-II condition.

CN (AMC-II) is decided for each HSCC unit and then modified for AMC-III condition using the following formula

$$CN\ (AMC-III) = 23 \times \frac{CN(AMC-II)}{10+0.13\times CN(AMC-II)} \quad (1)$$

Rainfall runoff (Q) map is prepared using the following equation modified for Indian condition (NIH, 1972)

$$Q = \frac{(P-0.1\times S)^2}{P+0.9\times S} \quad (2)$$

Where, P is the storm rainfall in mm and S is the maximum potential retention in mm, given by

$$S = \frac{25400}{CN} - 254 \quad (3)$$

The methodology for surface runoff estimation is shown in Figure 1. The same methodology is followed for future projected scenarios. Further basin wise assessment is done for Maharashtra state.

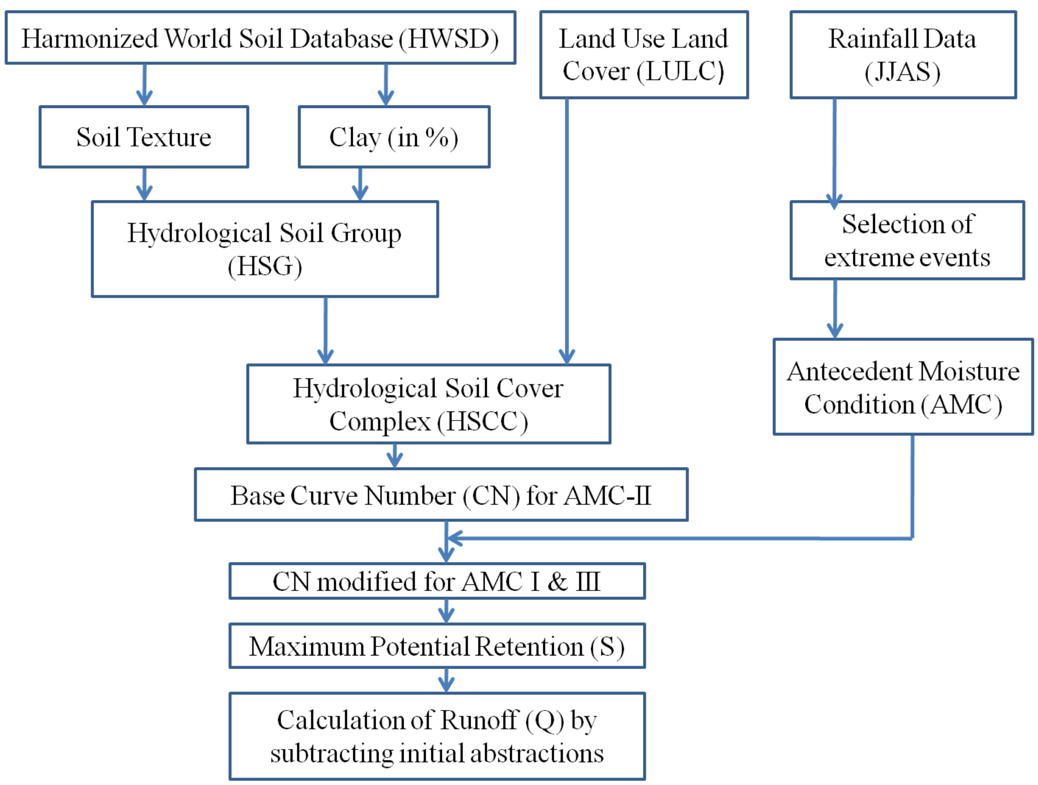


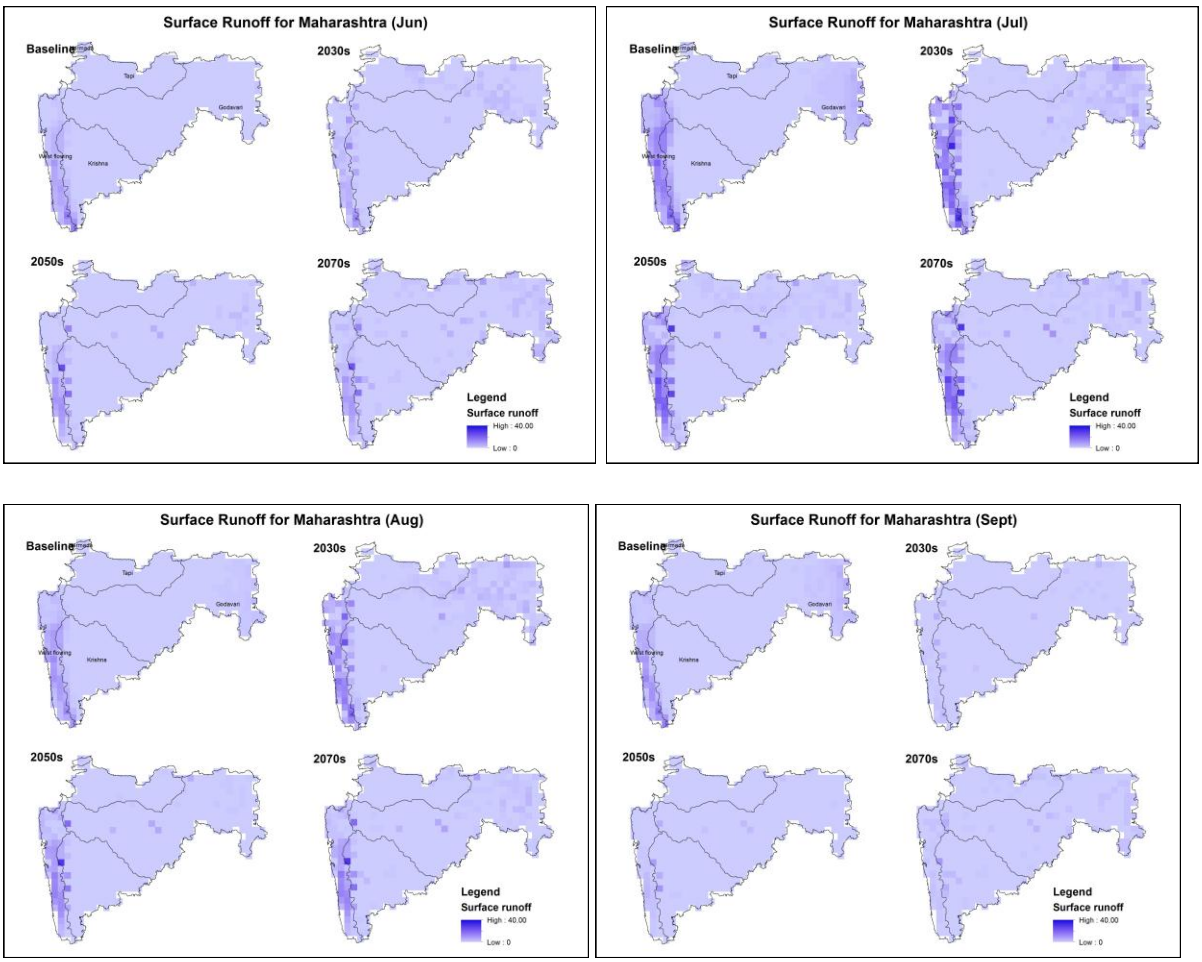
Figure 1. Methodology used to compute surface runoff for the Maharashtra State

9.2.2 Results

Among the five different basins Godavari, Krishna, West flowing, Narmada and Tapi, West flowing receives the maximum rainfall and corresponding maximum runoff depth is observed.

Spatial distribution of surface runoff calculated for the monsoon months for different time periods in the study area is shown in Figure 2.

In the baseline, surface runoff is highest in West flowing basin followed by Gondia and Gadchiroli regions, for all the monsoon months. Maximum surface runoff is observed in July month. Surface runoff is showing a gradual increase in 2030s, 2050s and 2070s in the respected areas as compared to the baseline. In future scenarios, some parts of central Maharashtra also show a slight increase in runoff. But on an overall basis, both mean rainfall and mean surface runoff shows an increase in the future projected scenario.



*units in Kg/m[2]/day

Figure 2. Surface runoff for monsoon months across different time periods (Baseline, 2030s, 2050s, 2070s) for Maharashtra State.

- Increase in rainfall projected for future time periods. Rainfall follows an epochal trend. Increase in rainfall is projected in the 2030s, with a decline in rainfall by the 2050s. However rainfall in the 2050s is still likely to remain above the baseline.

- Projected increase in rainfall in the form of heavy precipitation events.
- Increase in surface run off is projected in certain catchments eg., sub-catchments of Godavari are expected to have increased runoff in the month of July
- Increase in the number of low rainfall days in south central Maharashtra indicates dry periods in this region which is likely to have an impact on water resources

9.3 Adaptation needs and priorities for Maharashtra's water resources: ongoing government initiatives and limitations

Augmenting the stock of both surface and groundwater resources is one of the most important areas of government action in Maharashtra. Micro-irrigation is known to offer several benefits such as (a) arresting water logging; (b) resolving issues pertaining to secondary salinization in cultural command area; (c) check on receding water table; and (d) restoring water quality. With the establishment of National Mission on Micro Irrigation, additional agricultural land is targeted to be covered under micro-irrigation. In Maharashtra, the government has fixed the maximum retail price for micro-irrigation equipment[22] with a view to provide the micro irrigation equipment at reasonable rates to the farmers. This would help in a way that the more number of farmers can undertake micro-irrigation in their farms.

Under the Maharashtra Water Resources Regulatory Act, District Watershed Management Committees have been formed. These committees have been constituted to prepare the Integrated Watershed Development and Management Plan and mainly for the artificial recharge of groundwater. Hence there is a need to include aspects pertaining to irrigation such as including the dams and surface water bodies while developing the watershed management plan.

There is also a need to constitute policies and norms pertaining to irrigation, specific for each district. It was highlighted in the district consultations that the norms and regulations that were followed were formulated for the state. As the district has its own limitations and issues due to its geographical and topographical conditions, there was a need to devise norms specific to the district. The officials also highlighted the need to orient the irrigation policies to tackle impacts of climate variability. For instance, in Thane district, the officials informed that the dams currently in use for irrigation purpose need rehabilitation work. Large numbers of these dams were constructed few years back, which did not account for the increasing population. Hence these dams proved insufficient to provide water to the increasing population. Likewise, if the projected increase in rainfall was considered, there was an urgent need to increase the height of the irrigational structures, which also has issues owing to limitations posed by structural norms.

[22] http://www.mahaagri.gov.in/Schemes/displayGdet.aspx?id=269

There are a number of central and state government sponsored watershed programs ongoing in Maharashtra, many of which operate in drought-prone areas. Watershed development activities are being undertaken in the State under the State's Accelerated Watershed Development Programme, the Marathwada and Vidarbha Watershed Development Missions, the Artificial Ground Water Recharge Scheme (AGWRS), the National Watershed Development Programme for Rainfed Areas (NWDPRA), and the Rashtriya Krishi Vikas Yojana (RKVY). In addition, a number of nongovernmental organizations, including the Water Organizations Trust, the Bharatiya Agro Industries Foundation, Marathwada Sheti Sahyog Mandal, and Action for Agricultural Renewal in Maharashtra run their own watershed programs in limited pockets. Typically, the watershed programs include measures such as improved surface runoff collection structures, better groundwater recharge, drainage line treatment, and increases in vegetation cover.

"Shivkalin Pani Sathawan Yojana" (Shivkalin Water Harvesting scheme), the scheme for 'augmenting the availability of water for Drinking and Domestic use and Strengthening of Drinking Water Sources by utilising Rainwater' was initiated in 2002 by the GoM. Groundwater is the main source for drinking water in rural areas. Considering all the aspects for sustainable availability of drinking water from the water supply schemes, the scheme provides for conventional and non-conventional measures for drinking water source strengthening, roof-top rain water harvesting, construction of storage tanks in the hilly areas of the villages for storage of rain water and similar other measures.

Maharashtra is especially affected by an exploitation of ground water resources. The most effective measures in terms of groundwater recharge and cost effectiveness are recharge pits, farm ponds, and earthen and cement nala bunds (NRAA 2011). Farm ponds, village ponds, and water harvesting structures are also being constructed under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGS). More importantly, better management of dwindling groundwater resources requires regular and frequent measurement and monitoring. Nationwide dynamic groundwater resources assessment was last done in 2004. While the Groundwater Information System exists in Maharashtra, the data needs to be updated.

There have been successful examples in Maharashtra of water user associations and volumetric pricing of canal irrigation water. The Maharashtra Management of Irrigation Systems by Farmers Act (2005) has enabled the formation of legally empowered water user associations in the State. Water charges are collected on volumetric basis and the state achieved 100% cost recovery in 2002. The Maharashtra Water Resources Regulatory Authority Act (2005) has also brought efficiency in water resources planning in an integrated manner.

The Maharashtra Groundwater (Development and Management) Bill, 2009 calls for the setting up of a State Groundwater Authority and District-Level Authorities to manage and regulate groundwater usage in over-exploited areas, in partnership with local communities. The bill envisages registration of well owners, rainwater harvesting for groundwater recharge, registration of drilling rigs, declaration of water scarcity area, and prohibition of construction of well in certain areas. These legislative measures can be combined with installation of water meters on borewells/tubewells (and the rationalization of electricity tariffs). It is especially important – as is recognised by the Maharashtra State Water Policy – to curtail over-extraction of groundwater in the coastal districts of Sindhudurg, Thane, Raigad, and Ratnagiri in order to prevent salt water ingress.

Almost all cities in Maharashtra already face acute water shortages in the dry months. At present rainwater harvesting is mandatory for new buildings in Mumbai, Pimpri-Chinchwad, and Nashik. Given the projected increase in rainfall variability and the growing urban population of the state, water treatment and recycling by municipalities is essential. Given the issues of social acceptability of treated water, and the infrastructure cost of providing separate lines for non-potable water, the treated water can be used for groundwater recharge. A successful urban water initiative in this regard is that of the Badlapur Municipal Corporation, which has implemented an institutional eco-sanitation facility including recycling and reuse of waste-water, together with biogas plant and a horizontal flow constructed wetland system.

At present water shortage, rather than water prices, are the motivating factor for industries to invest in water recycling and reuse. Hence there is a need to institute a combination of regulatory and market-based measures to encourage water recycling and reuse by industries and municipalities.

9.4 Key recommendations for water resources sector

- Conservation and renaturalisation of rivers and water bodies
- Enhancement of water storage and groundwater recharge
- Improvement of water use efficiency

9.5 Adaptation action plan for water resources sector

- Retain and conserve the riparian zones and renaturalize existing wetlands in the state. Enhance native vegetation in these zones and formulate stringent policies to prevent the dumping of debris and waste in these zones.
- Modify the current tree policy to retain the mature trees, mainly around the origin of rivers which can help reduce soil erosion and downstream sedimentation. Hill areas where rivers originate can be declared as eco-sensitive zones and rewilded.

- Maintain the ecological flow in rivers both downstream and upstream of dams (20-30% of lean and non-lean period flows)
- Recharge underground aquifers through artificial recharge methods (such as percolation tank, recharge well, etc) in scientifically demarcated zones, by declaring green belt areas in urban areas, and by using paving materials that allow infiltration in urban areas.
- Prepare and implement action plan to augment water storage capacity in central Maharashtra to effectively harness the projected increase in rainfall for irrigation. Implement measures to conserve soil moisture for winter and summer crops, including improved planning and construction of watershed management structures like percolation tanks and check dams on rivers, tributaries, nalas, and downstream of dams based on sound technical assessment of aquifer conditions. Building the capacity of communities and local NGOs to maintain and operate projects under government schemes, and to build small decentralized water harvesting structures would help scale up such interventions and ensure that they are self-sustaining and locally appropriate.
- Promote efficient use of irrigation water in districts with plantation crops, such as Aurangabad, Amrawati, Bhandara, Nagpur, Nasik and Jalgaon, through continued subsidies for drip and sprinkler irrigation systems and farm ponds, combined with extensive awareness campaigns for smaller and less educated farmers.
- Mandate water recycling and reuse by industries and utilities, and encourage early adoption through tax concessions. Also mandate regular water audits by industries and utilities and raise the prices for fresh surface water. As a supplementary measure to reduce the costs of compliance, provide incentives to domestic wastewater treatment equipment manufacturers.
- Make rainwater harvesting mandatory in new and existing structures in all million-plus population cities of Maharashtra. Facilitate compliance by making information about contractors and technologies available in a centralized database, undertaking a demonstration project in each ward, and providing property tax incentives.
- Mandate treatment and reuse of sewage water for gardening or flushing
- Augment stormwater drainage infrastructure in major cities of Maharashtra to accommodate a 15% increase in flood magnitude due to climate change. The BRIMSTOVAD project in Mumbai can be replicated in other cities by raising finances through municipal bonds or pooled finance.

9.5.1 Adaptation Action 1: Sustainable ground water management

Action category: Focus on the policy framework and regulatory mechanisms of groundwater management along with capacity building of the end users and stakeholders, both in urban and rural areas, in monitoring the groundwater level as well as creating awareness among them.

Rationale: Currently, the groundwater management in the rural as well as urban areas is weakly structured and monitored. Several community members in the case study districts observed a steady increase in the number of wells dug in the last couple of years. Groundwater table has also been observed to drop down drastically, for instance in Solapur district, the extraction levels have gone to 500- 1000 meters as against 60 meters which is officially recommended by the government. Moreover, the vulnerability assessment study identifies extreme rainfall and percentage precipitation change as some of the key exposure indicators for future climate risks. Taking these future climate projections into consideration, it is proposed to address the issues pertaining to groundwater management for adequate water availability and equitable distribution.

Key components of the action:

- Mapping of groundwater sources through GPS technology in association with Groundwater Survey Development Agency – to give an overall illustration of number of wells in a particular region while integrating the geology and topology of the region. This would help in integrated water and land resources management
- Monitoring and regulating groundwater extraction – regular audits by the concerned departments/ local bodies, installation of water meters at groundwater sources, penalties in case of non-compliance
- Financial incentives for groundwater recharge infrastructure, including rainwater harvesting structures
- Preparation of guidelines for sustainable groundwater extraction, distribution and utilization
- Capacity building among the end users on self-monitoring of groundwater levels especially in the rural areas
- Creating water user associations and imparting training to them for improved groundwater management
- Creating awareness among the stakeholders about conserving groundwater resources as well as maintaining surface water bodies

Expected outcomes:

- Restored groundwater table/ levels
- Monitored groundwater extraction and hence check on number of wells dug
- Reduced unaccounted water extraction

- Equitable distribution of water – per household as well as sector wise such as drinking, domestic, agriculture, irrigation etc.
- Increased awareness about groundwater management

Implementation
Timeframe: 5 years

Links with ongoing govt. initiatives: The capacity building activities could be implemented through the network of programs of Rural Development Department such as 'Eco-village'. The water user associations which are currently focusing on irrigation sector could also be involved in groundwater management.

Nodal Govt. Departments

- Water Resource Department
- Water Conservation and Employment Guarantee Scheme Department
- Water Supply and Sanitation Department
- Rural Development Department
- Agriculture Department
- Urban Development Department

Specific capacity needs

- Special training would be required to train the water user association.
- Research professionals can be recruited to conduct research related activities

Choice criteria:
Strengthening the water resource management, can help build the adaptive capacity towards impacts of climate change while emphasizing on future climate risks. With projected scenarios of increased variability in rainfall and temperatures, it is imperative to conserve the ground and surface water resources to develop resilience in case of extreme events. Considering current development priorities of the state, integrated water resource management can help tackle existing issues pertaining to agriculture, drought, health and livelihood.

9.5.2 Adaptation Action 2: Retain and conserve the Riparian buffer around the wetlands for improved surface runoff management

Action category: Focus on research pertaining to the significance of riparian zones in the surface run off management; and building capacity amongst the key stakeholders including the government officials about the significance of such sensitive zones and their vital role played in safeguarding the ecosystem.

Rationale: Detailed consultations in the districts of the state, clearly state that there is an increased surface run off due to absence of sufficient vegetative cover in the state, affecting the existing water bodies (increased siltation) as well as the agriculture productivity (loss of fertile top layer). Districts like Nandurbar, where due to hard soil and steep terrain, projected increase in rainfall may not lead to increased groundwater recharge but may otherwise result in increased run-off while affecting the groundwater availability, absence of such buffer zones may likely add to the surface run offs and siltation. Likewise, in the district like Hingoli, where due to increased run-off after heavy precipitation events, there is an observed reduction in soil fertility in the region, the projected increased rainfall would exacerbate the existing vulnerabilities of the region. The riparian zones of the wetlands in any given region act as a buffer between the land and the water body, arresting the excess silt carried from the run off. In the absence of such zones, run off is expected to increased multifold. Thus, it's proposed to integrate the conservation and management practices of riparian zone in the overall surface run off management.

Key components of the action:

1. Re-naturalization of the existing wetlands in the state by breaking down the concrete embankments over the riparian zone and bringing the wetlands back to their natural state.
2. Introducing district level formulation of stringent policies to prevent the dumping of debris and waste in these zones thus avoiding the conversion of these wetlands into wastelands.
3. Improved vegetation of native species in these zones.

Expected outcomes:

1. Riparian zones, acting as buffer zones would hold the excess run off resulting due to heavy precipitation events.
2. The contaminant load can be reduced to a considerable extent.
3. Fertile layer, which may otherwise flow into the water bodies in the absence of the riparian zone could be retained.
4. Because riparian zones occur where major ecosystems – aquatic and land-based – meet, they provide habitats not found elsewhere which are important for the survival of a

number of native plants and animals. The dual objective of managing the preventing the soil erosion and retaining the local biodiversity can be achieved.

5. One of the solutions to achieving sustainable wetland use is to harness the natural abilities of riparian zones to absorb excess nutrients and to process waste materials before they enter watercourses. This provides the opportunity to manage riparian zones for the benefit of the water systems while still allowing productive use of the land and, potentially, the development of alternative forms of income.
6. Modify the current tree policy to retain the mature trees, mainly around the origin of rivers which can help reduce soil erosion and downstream sedimentation. Hill areas where rivers originate can be declared as eco-sensitive zones and rewilded.
7. Maintain the ecological flow in rivers both downstream and upstream of dams (20-30% of lean and non-lean period flows)

Implementation:

Timeframe	Short term: 1 gram panchayat from each case study block per district could be targeted for the pilot level implementation in next 3 years. Local participation could be encouraged.
	Long term: Dedicated policy for the conservation of the Riparian Zones in the urban and Rural in alignment with either the state lake conservation act or wetland rules.
Links with the ongoing activities	The Wetland Conservation Rules 2010, prohibits reclamation of wetlands, setting up/ expansion of industries, solid-waste dumping, effluent release from cities and industries. The conservation of the riparian zone could be undertaken in alignment with these rules in the state. CRZ notification 2011, restricting the construction activities in the coastal zone, protecting the ecologically sensitive and the geomorphological features which play a role in the maintaining the integrity of the coast.
Nodal Government Department	For urban wetlands, Urban Development Department, GoM. For Rural Wetlands: Rural Development Department, GoM For Lakes: Environment Department, GoM. For Wetlands in the forest areas: Forest Department, GoM.

	Overlooking agencies: Water resources and Agriculture department.

Choice criteria: The functions of wetlands and riparian areas include water quality improvement, aquatic habitat, stream shading, ground-water exchange etc. Wetlands and riparian areas typically occur as natural buffers between uplands and adjacent water bodies. Loss of these systems allows for a more direct contribution of upstream pollutants to receiving waters. As the study suggests an increase in the precipitation, especially in the Western Maharashtra, the run off from the upstream areas (urban or rural) is expected to increase. With the absence of sensitive zones like the riparian zones of the wetlands, situations like frequent flooding, inundation and damage to the local agriculture produce may seem to be on rise.

10. Agriculture in Maharashtra: climate change impacts and adaptation

10.1 Key trends in agriculture area, production and yield

Maharashtra occupies approximately 9.4% of the geographical area of India with a rural population of more than 52 million, which accounts for more than 58% of the total population of Maharashtra. A study conducted in 2000-01, which compared state with national figures, showed that while at the national level almost 59% of the workforce was employed in agriculture, the percentage population engaged in agriculture in Maharashtra was lower than the national average at 55 percent. On the basis of development indicators for Maharashtra (UNDP, 2011), 20.99% of the NSDP is contributed by the industry sector and 70.44 % of the NSDP is contributed by the services sector.(National State Domestic Product) With such almost 90% of the NSDP from industries and services, the agriculture sector that has a contribution of only 8.57% appears to one of the lesser important sectors for the state. However, although the share of workers in agriculture is lower in Maharashtra as compared to the national average, a district-wise analysis of the statistics present a completely different picture (Maharashtra HDR, 2005). Exclusion of the workforce from Mumbai alone causes a 7-8% increase in the proportion of workers in the agricultural sector. Moreover, in 2000-01, almost 20 out of 34 districts had more than 70 per cent of their workforce in the agricultural sector while 29 districts had more than 60 per cent workforce in agriculture. These percentages are more than those of the national average. This strongly suggests that barring a few districts like Mumbai, Thane, Nagpur and Pune which support large urban populations, the rest of Maharashtra's economy is predominantly agrarian and a major portion of Maharashtra's workforce is still dependent on agriculture as its primary source of livelihood.

Table 1: Some Demographic and Economic Indicators for Maharashtra (Source: UNDP, 2011)

No.	**Demographic Indicators**	**2011**
1	Total Population (In Millions)	112
2	% Contribution to national population	9.29
	Economic Indicators	
3	Net domestic Product (at factor cost) (Rs crores) (For state)	634828
4	Contribution of Agriculture to NSDP/GDP (%)	8.57
5	Contribution of Industry to NSDP/GDP (%)	20.99

No.	Demographic Indicators	2011
6	Contribution of Services to NSDP/GDP (%)	70.44

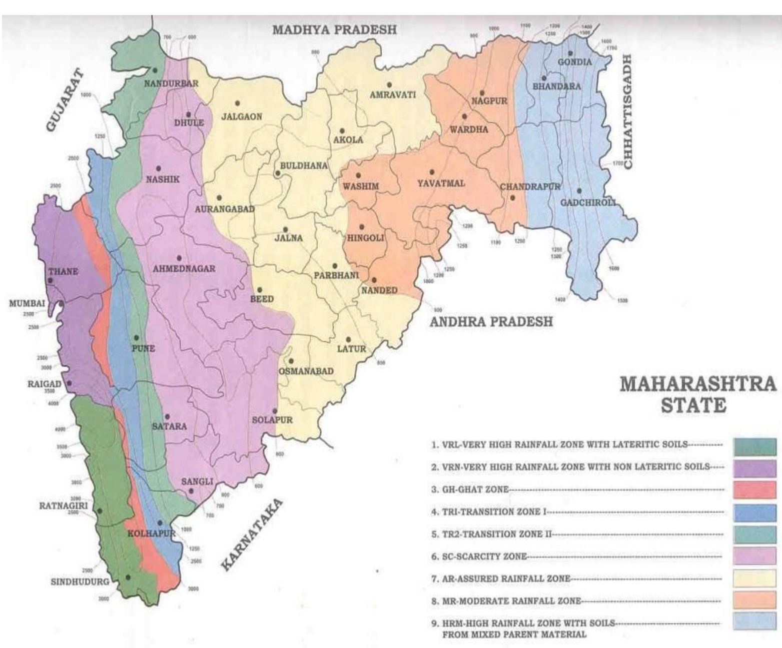
Therefore, the agriculture sector remains of crucial importance to vast majority of population throughout Maharashtra. In the light of climate variability and change, the sector requires greater focus as it is well established that the rural and the poor are the most vulnerable to the impacts of climate change. The performance of the agriculture sector depends largely on the natural resources. Climate change and variability further exacerbate the existing threats to agriculture. In addition to this, as it already well-established that the sector is of vital importance as it is the primary source of livelihood for the vast rural population, it requires greater focus in future policy and planning processes.

In order to assess the future implications of variability and changes in climate on agriculture, it is important to first understand the current or baseline conditions and trends that affect agriculture to understand the magnitude and direction of change that can be expected in the future. Keeping this in mind, the following section outlines the overall baseline scenario for better understanding of the current behavior of important factors that contribute to agricultural production in Maharashtra.

10.1.1 Geographical regions

The state is divided in six revenue divisions - Konkan, Pune, Nashik, Amravati, Aurangabad and Nagpur, which consist of 35 districts. In addition to this, the state is also divided into 9 agro climatic zones.

- South Konkan Coastal Zone
- North Konkan Coastal Zone
- Western Ghat Zone
- Submontane Zone



- Plain Zone
- Scarcity Zone
- Central Maharashtra – Plateau Zone
- Central Vidarbha Zone
- Eastern Vidarbha Zone

Figure 1: Agro-climatic zones of Maharashtra

These agro-climatic zones have been differentiated by virtue of their characteristics. The geographical distribution and the particular characteristics that distinguish each of the ACZs from one another are listed in Table 2.

Table 2: Characteristics of the main agro-climatic zones of Maharashtra

Zone	**Districts**	**Characteristics**
North Konkan coastal plain	Thane, Raigad	Very high rainfall in excess of 3,000 mm/year. High humidity in rainy season. Temperatures range between 22 – 30 degrees Celsius. Coarse alluvial non-lateritic soils poor in phosphorus and potassium. Rice is major crop. Vegetables and pulses also important. Small forest cover remains.
South Konkan coastal plain	Ratnagiri, Sindhudurg	Very high rainfall in excess of 3,000 mm/year. Precipitation dictated by S-W monsoon from June to September. Temperatures range from 20-30 degrees Celsius. May is the hottest month. Coastal alluvial lateritic soils rich in nitrogen and potassium and poor in phosphorus. Rice is major crop. Fruit trees also important.
Western Ghat mountain zone	Kolhapur, Satara, Pune, Ahmednagar, Nasik, Sindhudurg	Very narrow strip of highlands extending from North to South along the crest of the Sahyadri mountain range. Altitude varies from 1,000 to 2,000 masl. Very high rainfall in some areas in excess of 4,000 mm/year. Daily

Zone	Districts	Characteristics
		temperatures range from 30 to 40 degrees Celsius. Lateritic reddish brown soils low in phosphorus and potassium. About 25% area is under forest. Rice, sorghum, groundnut and fruit trees are important crops.
Sub- mountain transition zone I	Nasik, Pune, Satara, Sangli, Kolhapur	Narrow strip of lower elevation located in the eastern side of the Sahyadri range. Very wide range of rainfall varying from 700 to 2,500 mm/year dictated by the S-W monsoon. Day temperatures vary from 28 to 35 degrees Celsius. Soils are reddish brown to black, rich in nitrogen and poor in phosphorus. Important crops are kharif cereals, groundnut, sugarcane, vegetables, chillies and fruit trees.
Western plain transition zone II	Dhule, Ahmednagar, Sangli,Nasik, Pune, Satara, Kolhapur	Mostly a plain strip running North-South parallel to the eastern side of Transition zone I. Rainfall varies from 700 to 1,200 mm/year well distributed during the S-W monsoon. Maximum temperature will reach 40 degrees Celsius in the summer. Soils are generally light black, fair levels of NPK, well drained and suited for irrigation. Major crops are sorghum, millet, groundnut, wheat and sugarcane.
Western drought prone area	Dhule, Nasik, Aurangabad, Ahmednagar, Pune, Satara, Solapur, Sangli	Characterized by low and unpredictable rainfall of 500 to 700 mm/year in 40-45 days. Common dry spells will last from 2 to 10 weeks. Delayed onset and early cessation of S-W monsoon is very common. Summer temperatures will reach above 42 degrees Celsius. Soils are medium black vertisoils, coarse, shallow, and poor in nitrogen and phosphorus. Common crops are millet, sorghum, groundnut and pulses. Yields are low.
Central plateau assured rainfall	Aurangabad, Jalna, Beed, Osmanabad, Parbhani, Nanded, Buldhana, Akola, Amravati, Jalgaon, Dhule, Solapur	Large plateau covering the central part of the state. Well-distributed rainfall of 700 to 900 mm/year dictated by the S-W monsoon. Summer temperature will reach about 40 degrees Celsius. Soils are vertisoils and entisoils varying from medium black to reddish brown. Sorghum is the most important crop, but cotton, oilseeds, millet, groundnut, , pulses and sugarcane occupy significant areas.
Central Vidarbha moderate rainfall	Wardha, Nagpur, Yavatmal, Chandrapur, Aurangabad, Jalna, Parbhani, Nanded,	Rainfall of 1,200 mm/year well distributed within the S-W monsoon months. Maximum temperatures of 35-40 degrees Celsius in the summer. Humidity of about 75% in the rainy season. Soils are black derived from basalt rock, medium to heavy texture, and generally fertile. Cropping patterns involve cotton, sorghum, pulses, wheat and oilseeds.
Eastern Vidarbha	Bhandara, Gadchiroli,	Soils derived from parent materials of mixed origin are

Zone	Districts	Characteristics
high rainfall	Chandrapur, Nagpur, Gondia	reddish brown. Almost 50% of the areas under forest cover. Rainfall varies from 1,300 to 1,800 mm, well distributed in the monsoon months. Summer temperature will reach about 37 degrees Celsius. Humidity is about 75% in the rainy season. Rice, pulses, sorghum and oilseeds are important crops.

Source: Agricultural Statistical Information. Department of Agriculture. Maharashtra State. Part II, 2002. 267p.

10.1.2 Overall trends

Despite being known to be an industrialized State, agriculture and allied sectors are still predominant in Maharashtra. While the contribution of the agriculture sector to the state gross domestic product may have decreased over the years – having declined from 36 % in 1961-62 and 16 % in 2001-02 to 12.9% in 2012-13[23], it still continues to be the major source of income for most of the population. Out of 30.524 million of the state's rural working population, nearly 85% (26.05 million people[2]) are either engaged in cultivation or as agricultural labourers. This constitutes nearly 53%[2] of the state's total working population and establishes agriculture as a very important sector for ensuring the livelihoods of the majority of the population.

Though the net sown area under agriculture is 56.5 %[1] (2010-11), the proportion of gross irrigated area to gross cropped area in the State is fairly low at approximately 19.64 %. Thus, 80.24 % of the area under agriculture is directly dependent on rainfall. Nearly one-third area of the state falls under rain-shadow region where the rains are not only scanty, but also, erratic. The soil, topography, rainfall and climate in these regions are not exceedingly conducive to good agriculture performance, resulting in per hectare crop yields that are low as compared to national averages.

Agriculture in the state is dominated by foodgrains. Approximately 108 lakh hectares[1] of land is cultivated under foodgrains (2011-12). The main crops grown in kharif are sorghum, millets, pulses, rice and cotton and main crops in rabi are sorghum and wheat. Cotton, sugarcane and tobacco are important cash crops, which also support allied industries like textile mills and sugar refineries in Maharashtra. Maharashtra is the largest producer of cotton and the second largest producer of sugarcane in the country. A total of 10.22 lakh hectares (2011-12)[1] of land is harvested under sugarcane and 41.67 lakh hectares under cotton cultivation in the State. 33.6% (2009-10)[1] of the total area under cotton cultivation in the country is in Maharashtra. 60% of the total cotton is produced in Vidharbha, 25% in Marathwada, 10% is produced in Khandesh and the remaining 5 are distributed over the state. Cotton is another most important cash crop in Maharashtra. Out of the total cultivation of cotton in the country, 36% of the total area is in Maharashtra. Maharashtra ranks second in the state-wise cultivation of sugarcane. The

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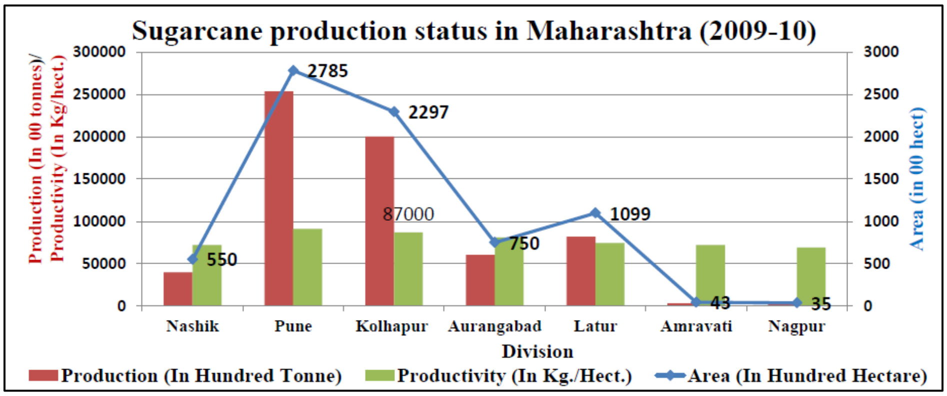
[23] Economic survey of Maharashtra 2012-13, Directorate of Economics and Statistics, Planning department, Government of Maharashtra, Mumbai

[24] Provisional Census of India – Maharashtra, 2011

cooperative sugar industries linked with this crop constitute the main factor of agriculture growth in the State. Furthermore, Maharashtra is one of the leading states in Bajra production as well. It is observed that the productivity of the Bajra in the state is high and is seen to be increasing over the years despite the decrease in the area and production.

Figure 2: Total area vs production of Sugarcane in Maharashtra



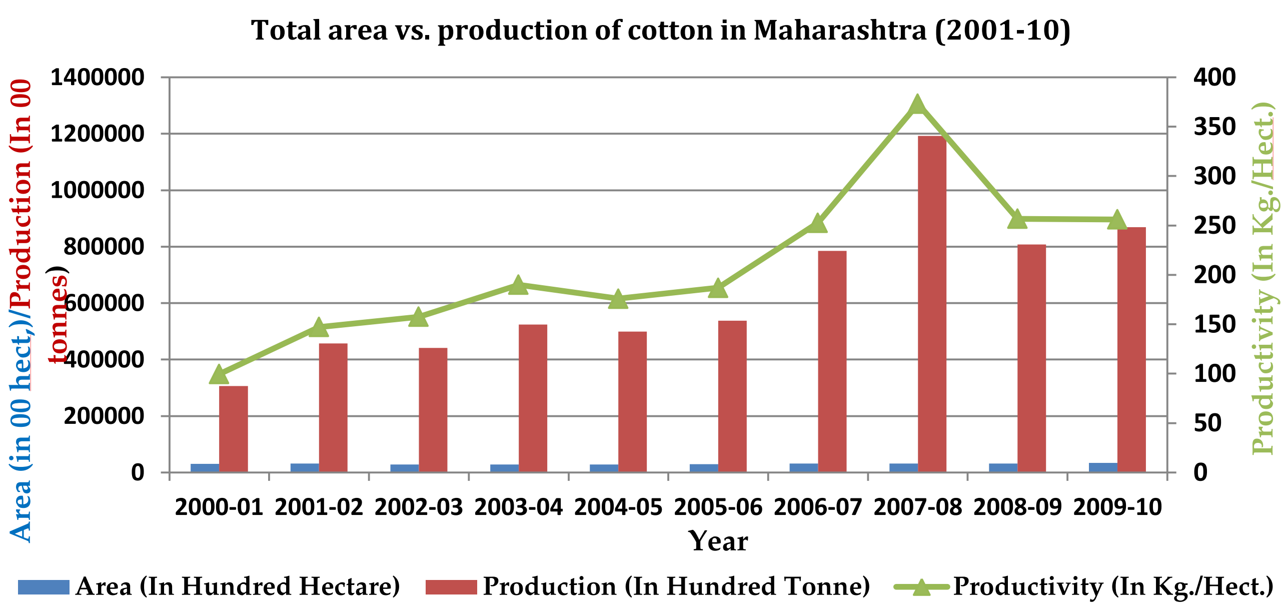


Figure 3: Total area vs production of cotton in Maharashtra

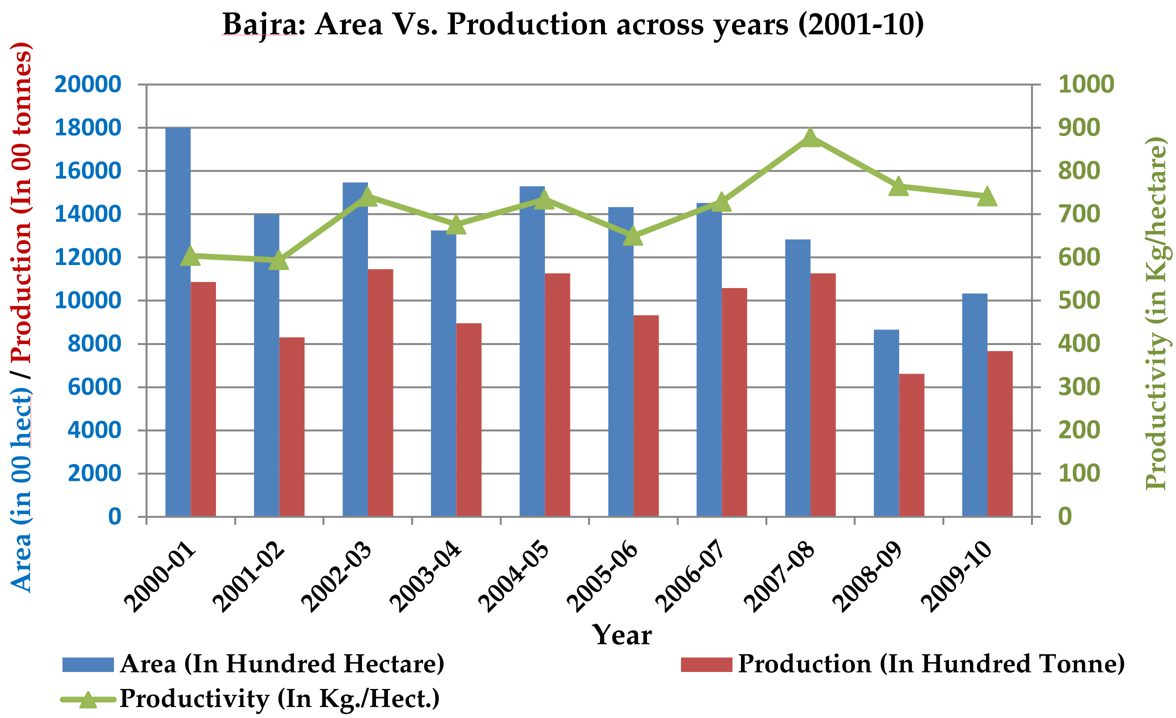


Figure 4. Total area, production and yield of bajra (2001-2010)

Foodgrains production has increased over time from 5.41 million tonnes in 1970-71 to 12.72 million tonnes in 2011-12[1]. The area under high yielding variety seeds (HYVs) in the state increased more than twenty times while irrigated area increased from 12.20 lakh ha (1960-61) to 33.74 lakh ha. (1999-00). The fertilizer consumption increased from 150 thousand tonnes (1969-70) to 1931 thousand tonnes (1999-00) in which per hectare consumption of fertilizer increased about 10 times.

While the gross cropped area as well area under foodgrains have increased over the years, the percentage coverage of 69 % of the GCA was under food grains in 1980-81 it has dropped to 56% in 2010-20111. The decline was prominent for cereals with considerable decline in the area and production of jowar was observed. Increase in area under pulse crops has been prominent and shift from foodgrain and forage crops towards cash crops is being observed. Increase in area has been observed for cotton, sugarcane, oilseeds. Marked increase in fruit and vegetable crops has also been observed in the recent years. Despite these shifts the area under cereals still constitutes a larger acreage compared to other crops, with a contribution of 25.5% to the agricultural SDP. In comparison, small area under sugarcane and fruits and vegetables contributes significantly to the SGDP.

Crop	1980-81 to1989-90	1990-91 to 2000-01	1980-81 to 2000-2001
Rice	0.58	-0.65*	0.17
Wheat	-2.30*	3.50**	-0.76
Bajra	2.40	-0.80	0.50*
Jowar	-0.37	-1.69**	-1.40**
T Cereals	0.07	-0.67	-0.69*
T Pulses	2.70*	0.91	1.69*
T Foodgrains	-0.27	0.61*	-0.15
Sugarcane	1.70**	2.40**	3.80*
Cotton	0.35	2.60*	1.14*
Oilseeds	6.70	0.60	2.70*
Fruits and vegetables	6.20	8.00*	6.50*

*1 % significance ** 5% significance

Table 3: Change in Area under Crops for different time periods

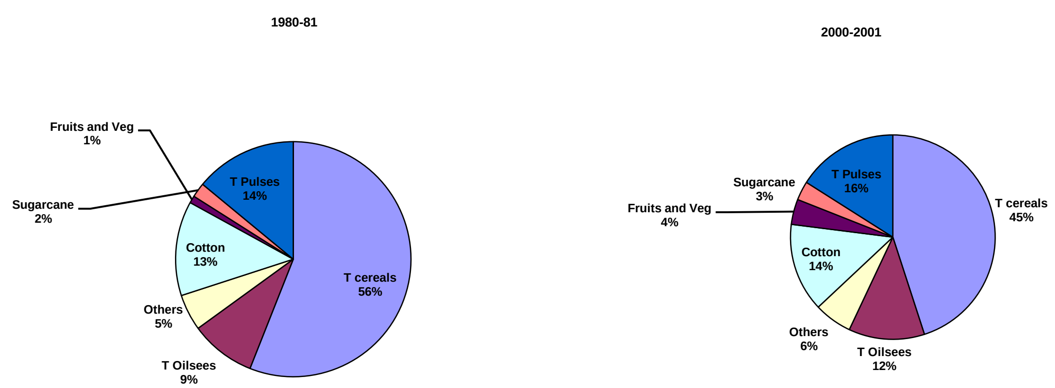


Figure 5: Area under various crops and change over time

Crop	1980-81 to1989-90	1990-91 to 2000-01	1980-81 to 2000-2001
Rice	-0.40	-0.13	0.7
Wheat	-0.40	3.7	2.03*
Bajra	1.40	-2.2	0.16
Jowar	4.40	0.55	4.60*
T Cereals	1.20	-0.5	1.1
T Pulses	7.20*	3.2	3.9
T Foodgrains	1.90	-0.01	1.5*
Sugarcane	9.20*	4.3**	6.08*
Cotton	3.30	3.8	4.20*
Oilseeds	0.64	4.2*	3.6*

*1 % significance ** 5% significance

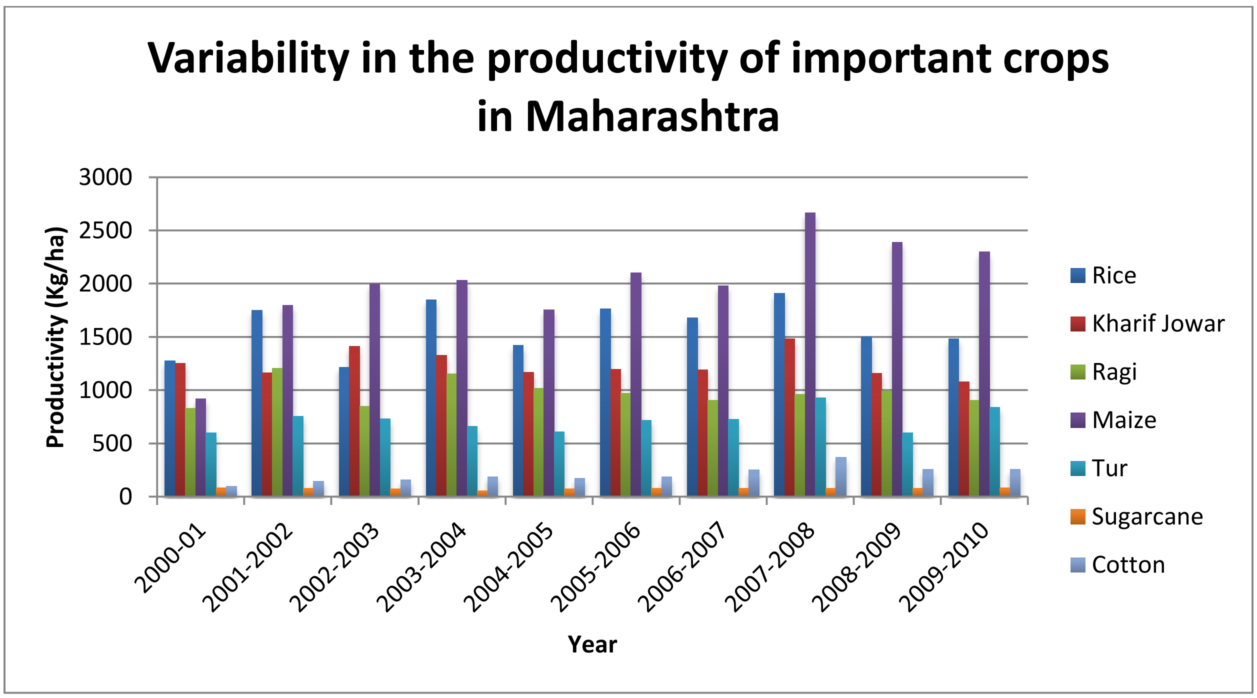
Table 4 : Growth in Production for Various Crops in the State

Crop	1980-81 to1989-90	1990-91 to 2000-01	1980-81 to 2000-2001
Rice	1.5**	-1.4	0
Wheat	2.3	1.5	2.7
Bajra	1.6	-0.4	1.6
Jowar	2	1.4	4.1
T Cereals	1.1	0.39	-0.06
T Pulses	4.6	2.3	2.3
T Foodgrains	1.3	0.48	1.6
Sugarcane	1.6	4.2	3.1
Cotton	3.1	1.5	3
Oilseeds	-1.4*	0.7	-0.58

*1 % significance ** 5% significance; Source: Maharashtra Development Report, Planning Commission 2007

Table 5: Growth in productivity of Various Crops in the State

While the overall productivities of most crops have increased over the years, the yield of pulses has only improved after 2000-01[1](see Figure 6 below). An upsurge in horticulture crops has also been observed in the recent past.



The State reports highest production and productivity rates of banana in the country with a growth in area of nearly 6.5 % [25] between 2001 and 2005 although there has been a slight decline in the productivity over this time. Maharashtra is also known for production of citrus fruits like mandarin and sweet oranges and lime. However, while the area under cultivation of horticultural crops has increased productivity rates have fallen over time. Maharashtra has also

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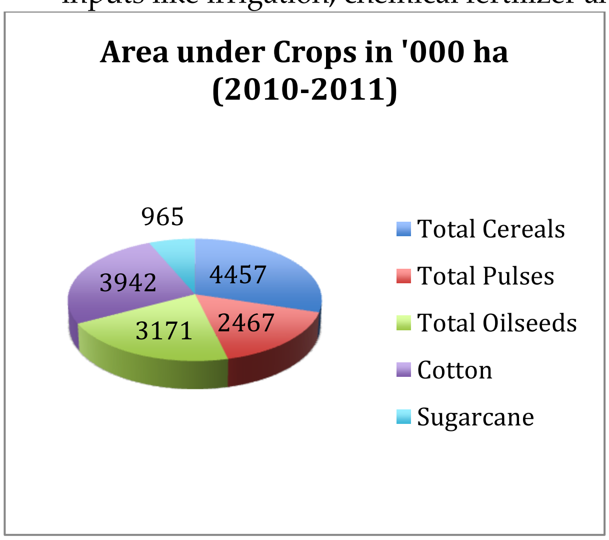
25 http://planningcommission.gov.in/aboutus/committee/wrkgrp11/wg11_aghorti.pdf

observed a significant increase in area and production – about 10.4% and a marginal increase in the productivity of grapes over the first half of the previous decade. Other crops grown that have experienced an increase in acreage but a significant decline in productivity include guava and mango.

The state also leads in the growth of vegetable crop like onions. It ranks the highest in terms of acreage in the country though the yield is lower than some of the other states. In the recent past, fluctuations in area, production and yield of onion has been observed in Maharashtra. Tomatoes are also grown and the productivity rates reported in 2004-05 indicate the highest productivities ranked in the country.

It is observed that the growth in area of major crops in the state reveals a mixed trend. Except for jowar, bajra and wheat all other crops recorded a growth in area. The growth in production and productivity of all these crops was visible during 1971-72 to 1980-81 – which can be attributed to the impacts of the green revolution, whereas commercial crops recorded remarkable increase during 1981-82 to 1997-98. There has been growth in the use of crucial inputs like irrigation, chemical fertilizer and high yielding variety seeds.



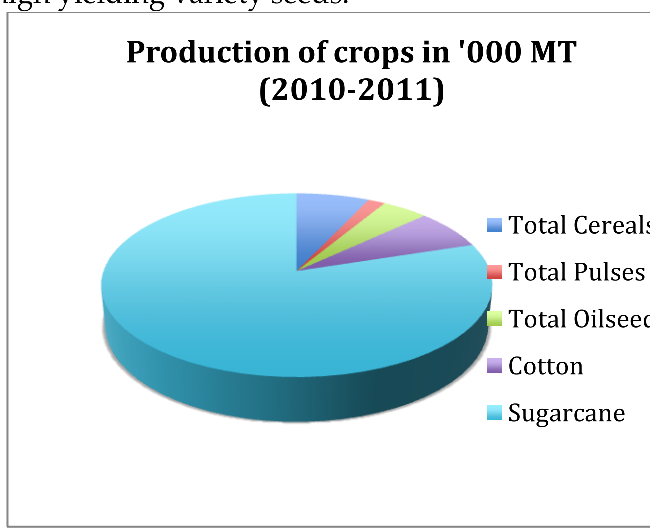


Figure 7: Area under crops & production of crops in 2010-11

In 2010-2011, the area under cultivation 15.002 million ha) occupied 50% of the total physical area of the state (30.8 million ha). In 2009-2010 the total irrigated area in Maharashtra (4 million ha) was only 17.9% of the gross cultivated area (22 million ha). In 2010-2011, Food crops, including cereals and pulses, occupy 6.9 million ha (46.9 % of the gross cultivated area), while sugarcane and cotton occupy 4.9 million ha (32.7% of gross cropped area). In 2010-2011 the most important crops in Maharashtra are Rice, Pulses, Cotton, Sugarcane, Soyabean etc. whereas in Rabi, Jowar, Wheat and Gram are important crops with the highest productions (Economic Survey of Maharashtra, 2011).

The scenario is much different from the last decade where in 1998/99, the area under cultivation (17.8 million ha) occupied 58% of the total physical area of the state (30.8 million ha). In the same year the total irrigated area in Maharashtra (3.9 million ha) was only 18% of the gross cultivated area (21.6 million ha). Food crops, including cereals and pulses, occupied 13.4 million ha (62 % of the gross cultivated area), while sugarcane and cotton occupied 3.8 million ha (18% of gross cropped area). The most important kharif crops were sorghum, millets and rice among the cereals, and grams and pigeon pea within the pulses and wheat and Gram were the most important rabi crops. Oil seed crops such as soybean, groundnut, sesame and mustard occupied large areas during kharif season (MWSIP, 2004).

It is quite apparent that with the increase in cultivation of water-intensive crops like cotton and sugarcane over the decade, water for irrigation has emerged as a crucial issue. The increasing demand for irrigation water directly relates to demands for better agricultural productivity, farm incomes and rural employment. However, there are several constraining factors that restrict the desired growth of agricultural productivity. Few of them are the low fertility of soils and limited area under irrigation. In addition to this, increase in the already large extent of degraded land, recurrence of droughts across large areas, slow filtration of improved crop and soil management practices among the farmers also lead to decreased realization of agricultural productivity (MWSIP, 2004).

Due to limited area under irrigation, majority of the rainfall is dependent on the rainfall and since the maximum rainfall period is during the monsoons (June to September), the Kharif season is the most important growing season for the state. Presently irrigation is to the tune of 15%, which can increase up to 23% only. Hence, more than 75% area will remain dependent on rainfall. Water requirement of sorghum is 250- 450 mm, pearl millet 200- 350 mm, rice 1200 mm and wheat 450 mm, while for sugarcane it is 2500+ mm. Hence, rainfall is sufficient to raise all crops except sugarcane which needs irrigation. Further, productivity of cereals, pulses and oilseeds can sustain, if one or two protective irrigations are provided.

Rainfall: Spread across an area of 30.76 million hectare, Maharashtra receives a mean annual rainfall of 1464.0 mm, which is significantly higher than the national mean average rainfall at 1094.4 mm. The state is divided in 4 meteorological subdivisions. They are the Konkan and Goa, Madhya Maharashtra, Marathwada and Vidarbha sub-divisions.

Maximum rainfall is experienced during the monsoon season in the months of June, July, August and September. Based on assessment by the Agricultural meteorology department of Mahatma Phule Krishi Vishwavidyalaya, in the past decade 1991-2000, the Konkan received 2998 mm, Madhya Maharashtra received 902 mm, Marathwada received 844 mm and Vidarbha received 1113 mm as mean annual rainfall. Among the 4 subdivisions, the Konkan and Goa get the maximum rainfall (Table 3). Rainfall is high in the North Konkan, South Konkan, Western Ghat and Eastern Vidarbha Zone but among these region the North Konkan region has high variability in rainfall.

The trends of rainfall in different regions of Maharashtra indicate that it is declining in Konkan slightly and in Madhya Maharashtra sharply during monsoon season and increasing in post monsoon season. Thus, annual rainfall is not affected much. But, kharif crops productivity is affected adversely. Increasing trend in post monsoon season in whole Maharashtra increases black mould in sorghum and favors incidence of Heliothis spp. in cotton and red gram (MPKV).

Table 6: Season wise mean rainfall in different regions of Maharashtra state and its percentage with the mean annual rainfall

Region	Jan-Feb		Mar-May		June-Sept		Oct-Dec		Annual
	mm	%	mm	%	mm	%	mm	%	mm
Konkan & Goa	2.0	0. 4	48.0	1.6	2801. 0	93.4	147.0	5.0	2998.0
Madhya Maharashtra	6.0	0. 6	45.0	4.9	745.0	82.6	108.0	11.9	902.0
Marathwada	6.0	0. 8	36.0	4.2	717.0	85.0	85.0	10.0	844.0
Vidarbha	24.0	2. 1	40.0	3.6	975.0	87.7	74.0	6.6	1113.0
Maharashtra	10.0	1. 0	42.0	3.6	1309. 0	89.4	103.0	8.4	1464.0

From 1970 – 2000 there have been several drought years where the rainfall was less than adequate and crop production suffered. Table 4 gives the drought years and the amount of area affected. However, none of these experienced the same severity as that of drought of the present year (2012). If popular opinion is believed, the severity of the current drought is next only to the drought of 1972. In Table 4, a moderate drought: 26< D <50%, Severe drought: D < 50%.

Table 7: Years of drought in last thirty years (1970- 2000) and area affected

Years	Moderate drought (%)	Severe drought (%)
1972	36.6	3.8
1974	27.1	6.9
1979	33.0	1.8
1982	29.1	00
1985	25.6	6.7
1987	29.8	17.9

Statistics show that despite lack of adequate water for irrigation and recurrent droughts in the state, the agricultural production has been more or less stable in the state. As presented in Table 8, in the decade of 1991-2001, all crop categories, which include, cereals, pulses, oil seed, cotton and sugarcane; have corresponded to the increase in rainfall with an increase in agricultural productivity.

Table 8: Productivity (kg/ha) of Important Crops in Maharashtra (Source, MPKV)

Year	**Total rainfall**	**Cereals**	**Pulses**	**Oil seed**	**Cotton (Lint)**	**Sugarcane**
1991-92	1236.6	857.7	418.0	479.8	71	80130
1992-93	1245.5	1236.1	542.0	653.1	125	76720
1993-94	1445.3	1212.4	724.0	759.6	180	81000
1994-95	1357.1	1148.0	550.0	645.4	145	85680
1995-96	1186.5	1167.5	554.5	667.9	155	83800
1996-97	1260.6	1333.2	670.5	756.4	174	81830
1997-98	1389.4	993.0	380.0	544.8	95	83000
1998-99	1593.4	1244.9	712.5	728.3	139	89000
1999-00	1316.8	1170.0	838.5	709.4	162	90000
2000-01	1401.1	947.9	561.0	608.7	100	83000

10.1.3 Trends in coverage of selected crops

Data from the department of agriculture was used to analyse the changes in acreage of important crops in Maharashtra in the administrative areas that they are primarily grown in. The crops selected were rice, jowar, sugarcane, cotton and soybean and the divisions, which have maximum area under cultivation, were selected (Table 16.8). Based on that, the administrative divisions, which had more than one crop interest being grown, were selected for analysis of the change in acreage of the selected crops within each administrative division from the year 2000-01 to 2009-2010 (Table 9).

Table 9 Administrative divisions with maximum coverage

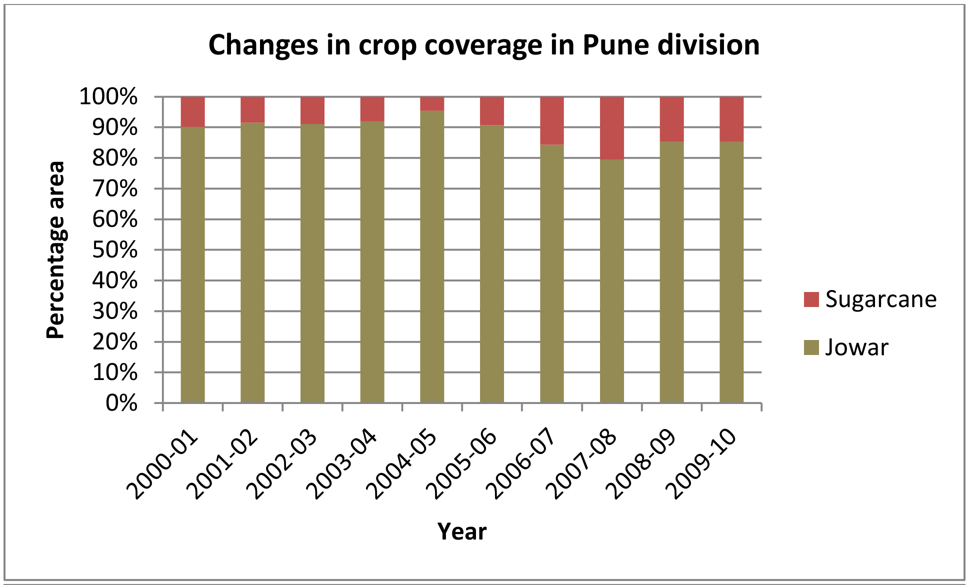
Crops	Administrative divisions				
Rice	Konkan	Nagpur	Kolhapur		
Jowar	Pune	Aurangabad	Latur	Kolhapur	

Crops	Administrative divisions				
Sugarcane	Pune	Kolhapur	Latur	Aurangabad	
Cotton	Amravati	Nasik	Latur	Aurangabad	Nagpur
Soybean	Nagpur	Amravati	Kolhapur		

Table 10 Administrative divisions and major crops

Administrative divisions	Major crops grown
Pune	Jowar and Sugarcane
Kolhapur	Rice, Jowar, Sugarcane and Soybean
Aurangabad	Jowar, Sugarcane and Ciotton
Latur	Jowar, Sugarcane and Cotton
Amravati	Cotton and Soybean
Nasik	Cotton
Konkan	Rice

Based on the division wise distinction, the percentage area and absolute area of the selected crops were mapped to depict the changes in their coverage over the decade and observe the overall trends. The results of analysis are presented in Figure 8 (a to f).



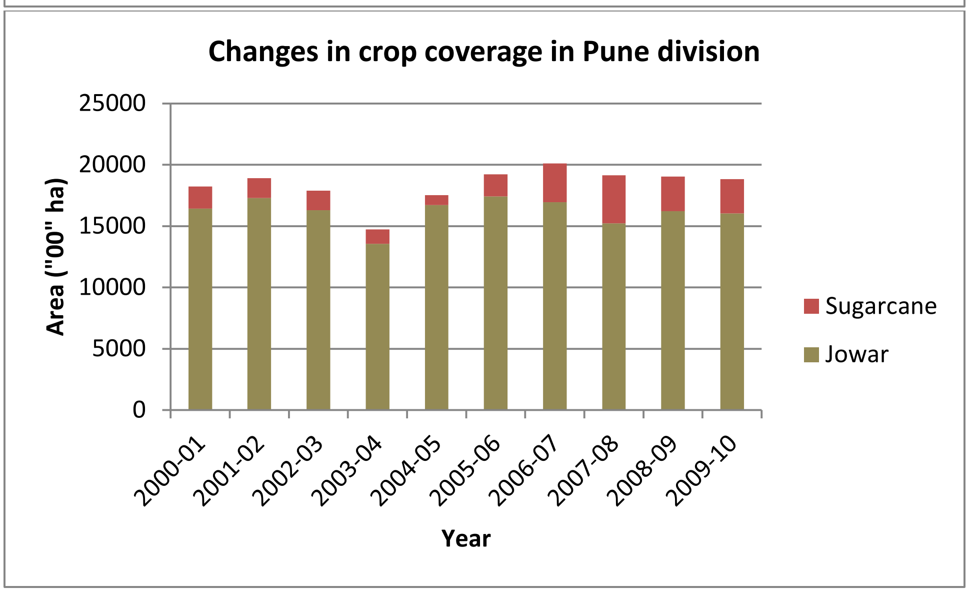
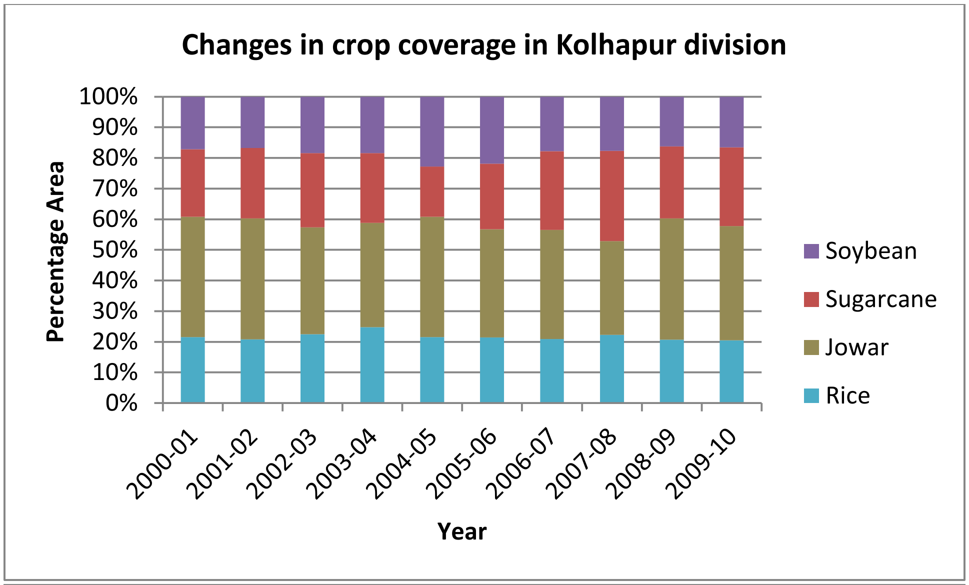


Figure 8 a) Pune division

In Pune division, a marginal decrease in Jowar area and a slight increase in Sugarcane area was observed.



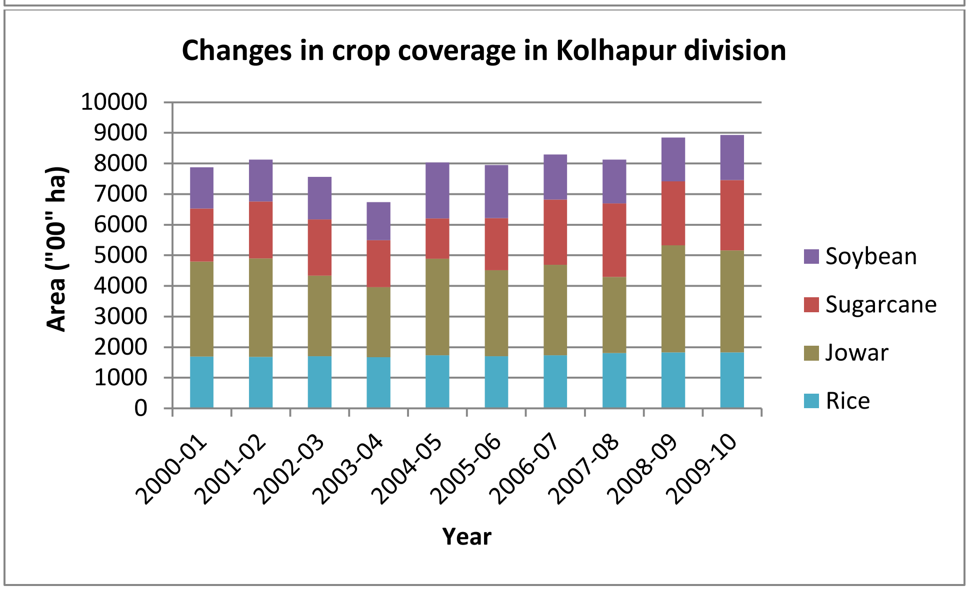
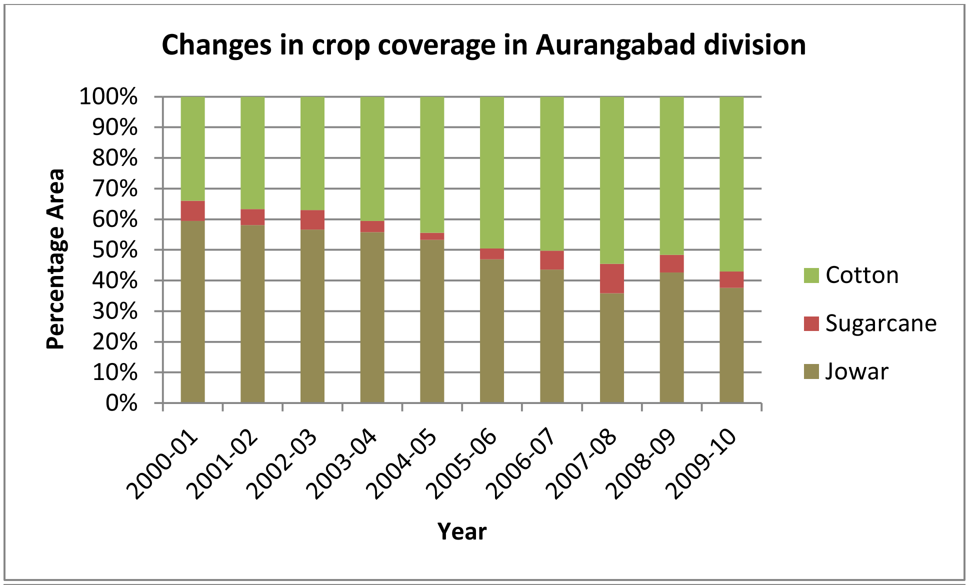


Figure 8 b) Kolhapur division

In Kolhapur division, a slight increase in rice and soybean and an increase in sugarcane and jowar was observed.



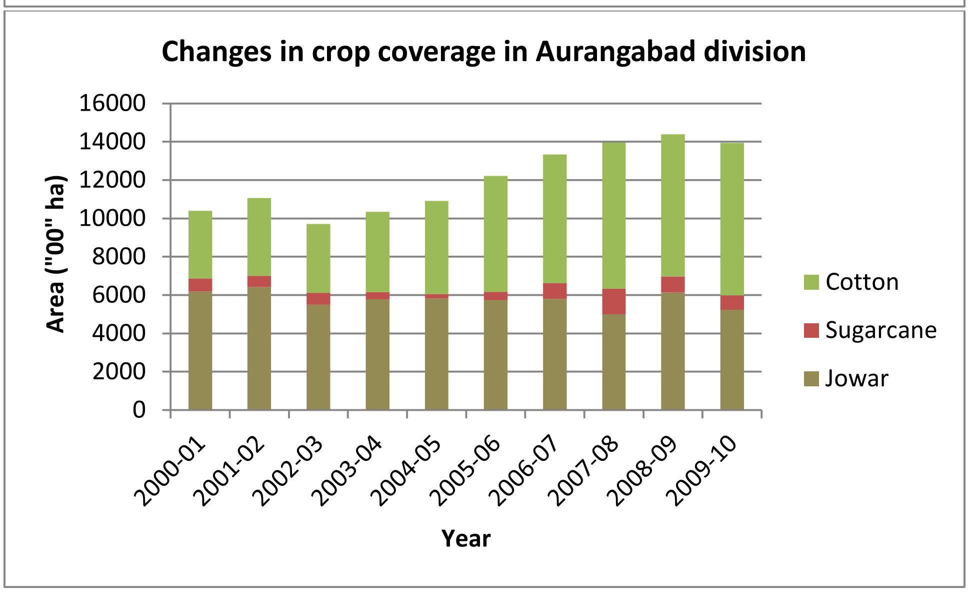
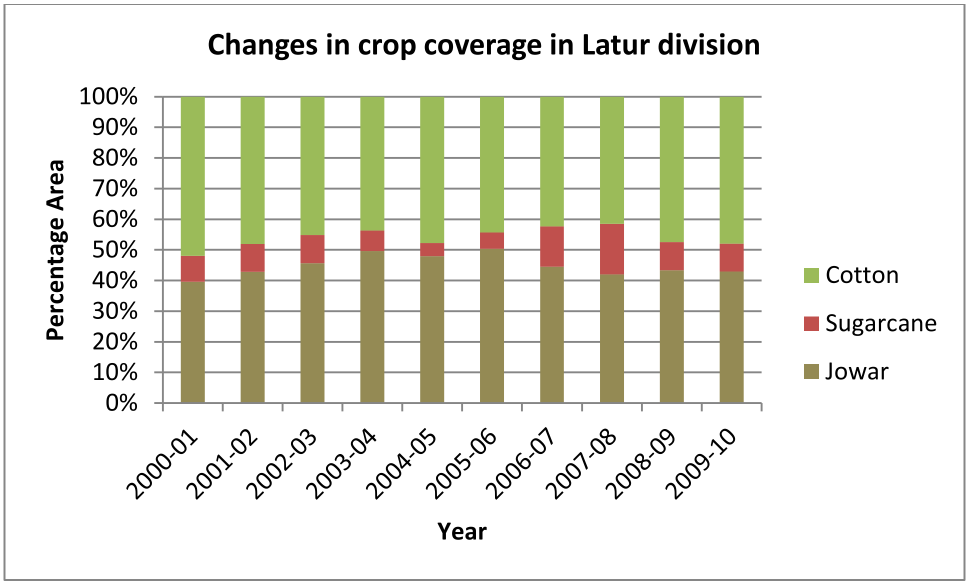


Figure 8 c) Aurangabad division

In the Aurangabad division, substantial increase in cotton and decrease in jowar area was observed.



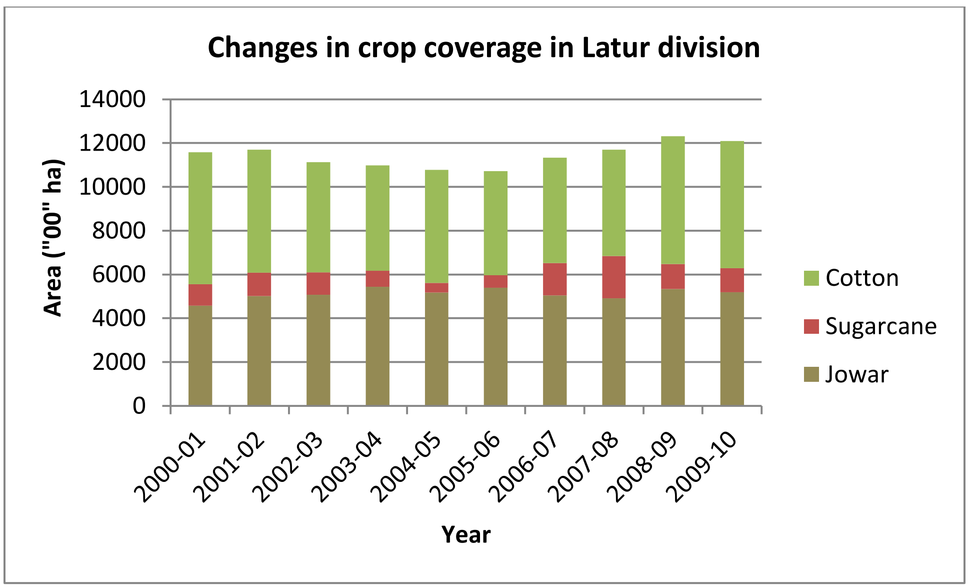
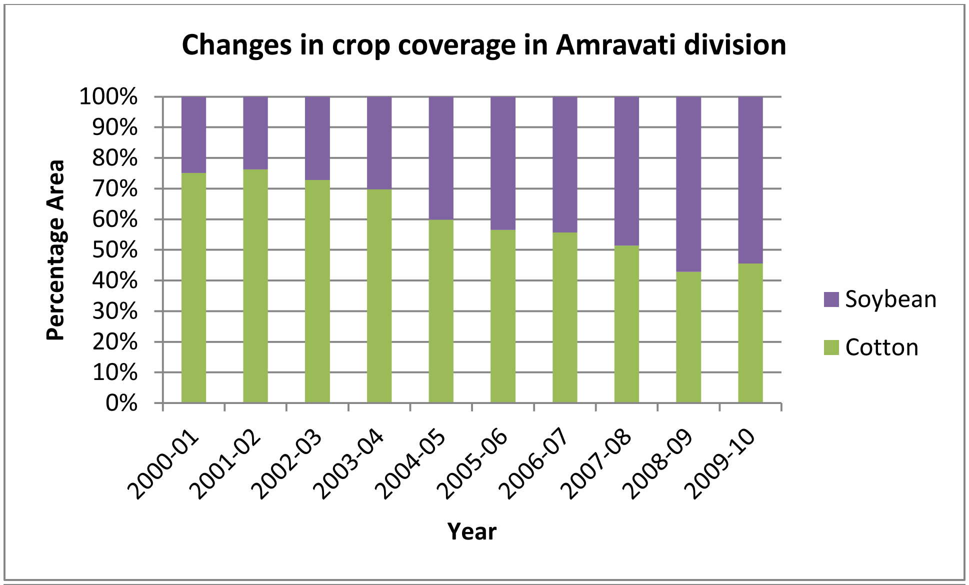


Figure 8 d) Latur division

In Latur division, a slight increase in cotton acreage was observed.



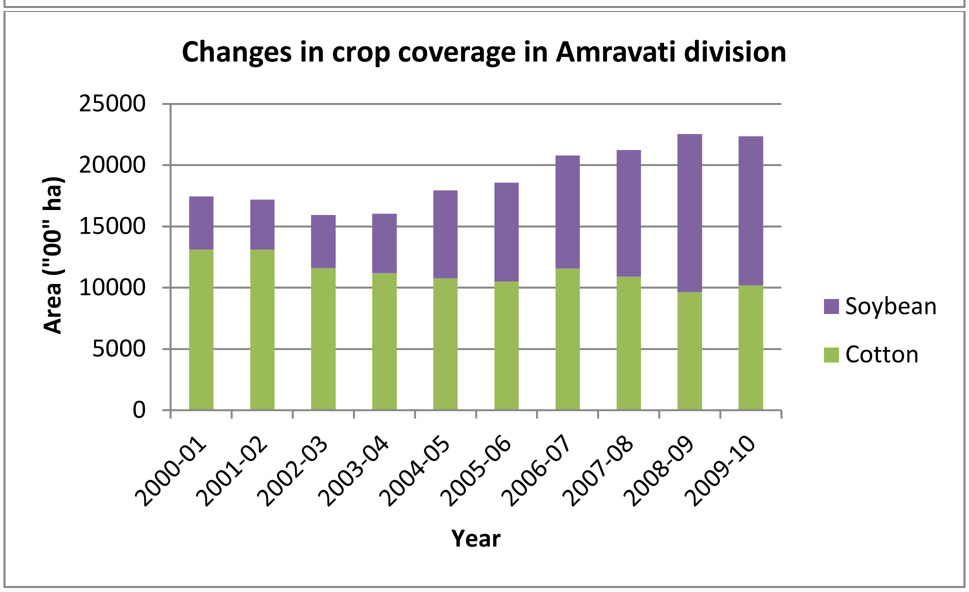


Figure 8 e) Amravati division

In the Amravati division, a very clear trend of increase in soybean acreage and decrease in cotton acreage was observed.

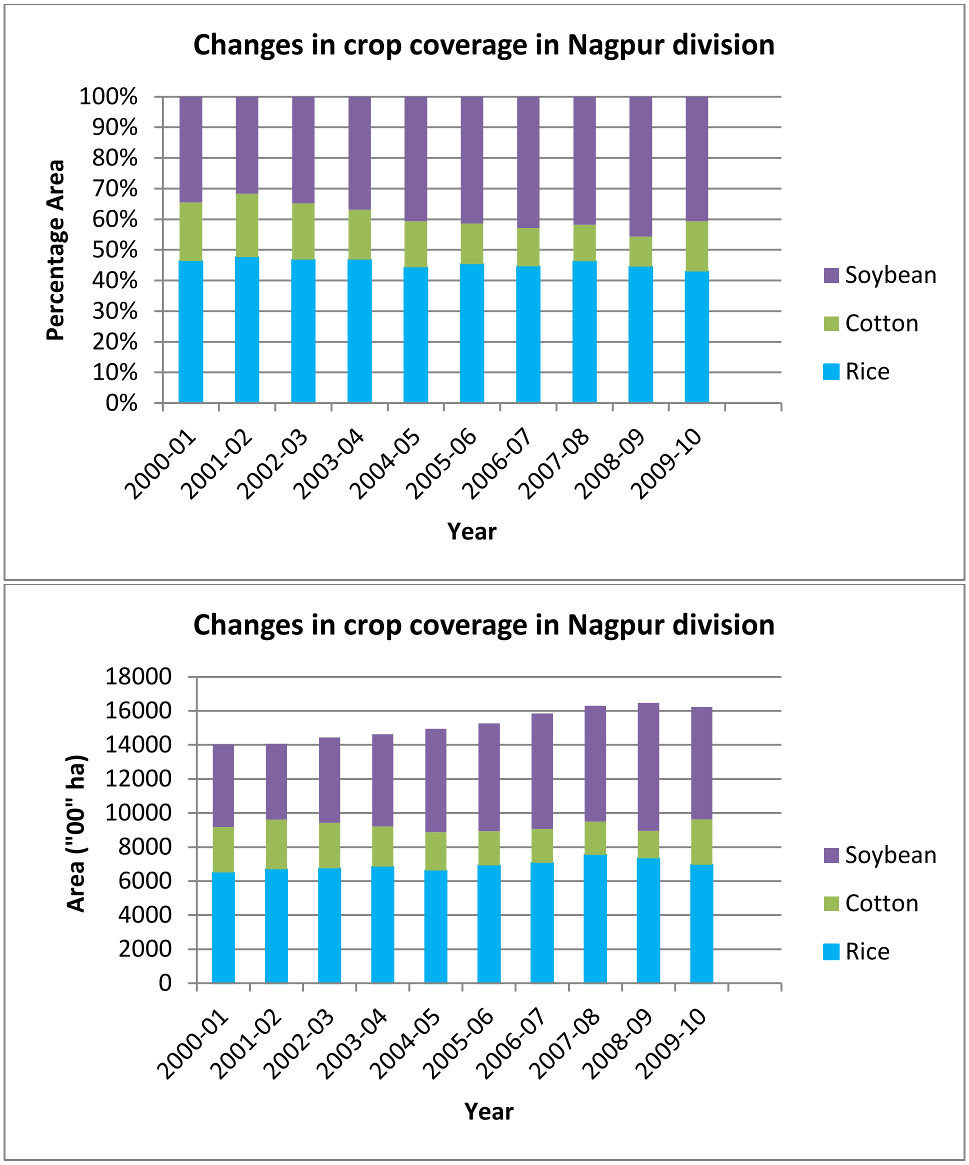


Figure 8 f) Nagpur division

In the Nagpur division, significant increase in soybean acreage and slight increase in rice acreage was observed.

10.2 Analysis of climate thresholds for selected major crops produced in Maharashtra state

Consequent to analysing the production trends of crops and their correlation with rainfall, a second approach was employed. This approach focussed on carrying out a threshold analysis of the specific important crops of the state by evaluating the threshold values for temperature and rainfall/ precipitation of the selected crops with the average annual and future projections in the given specific district. This approach helped in identifying the crops which are climate sensitive as well as those which are being cultivated on a larger scale. The crops which are sensitive are gradually being excluded by farmers from their cropping cycles and hence initiatives could be taken to revive the production of these crops, which are mainly the traditional crops of the region, and form an integral part of the staple food of the respective region. In some of the community consultations of the case study districts, it was observed that these traditional crops are being replaced by market driven resource intensive crops, owing to their high value. Hence to identify such trends especially in case of crops which are sensitive to climate variability, the threshold analysis was carried out.

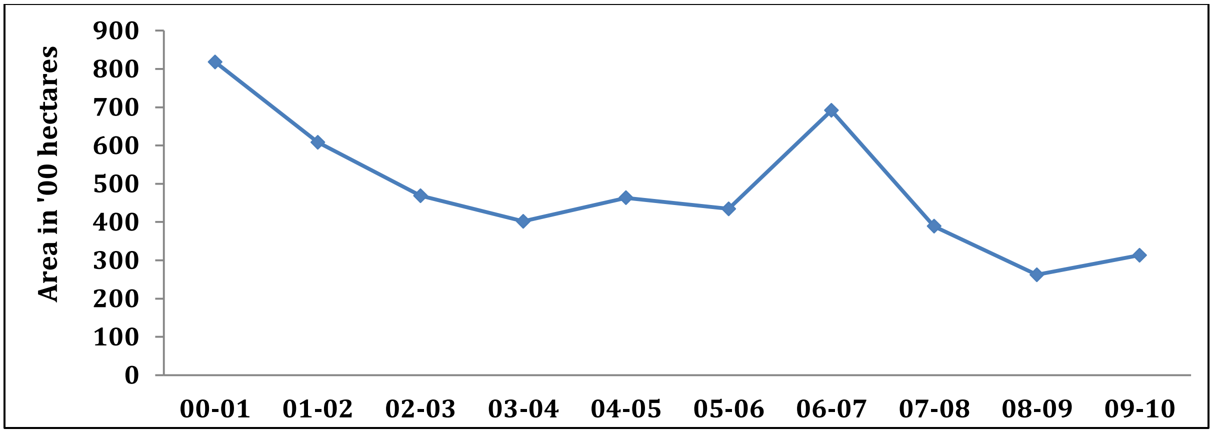
10.2.1 Methodology

To conduct the threshold analysis, the crops and districts were selected based on two indicators, namely

1. Crops exhibiting decreasing or increasing trend in terms of area under cultivation
2. District having largest area under cultivation of the selected crop

The rationale for including area under cultivation for selecting the crop was to identify the crops that are gradually being cultivated to adapt to the changing climate or for other factors such as better revenue generation. Once the crops were identified, the following indicator helped identify the district which showed a distinct decrease or increase in area under cultivation. For e.g. the area under bajra (pearl millet) cultivation is decreasing consistently since 2004-05 across the state, as shown in the graph below.

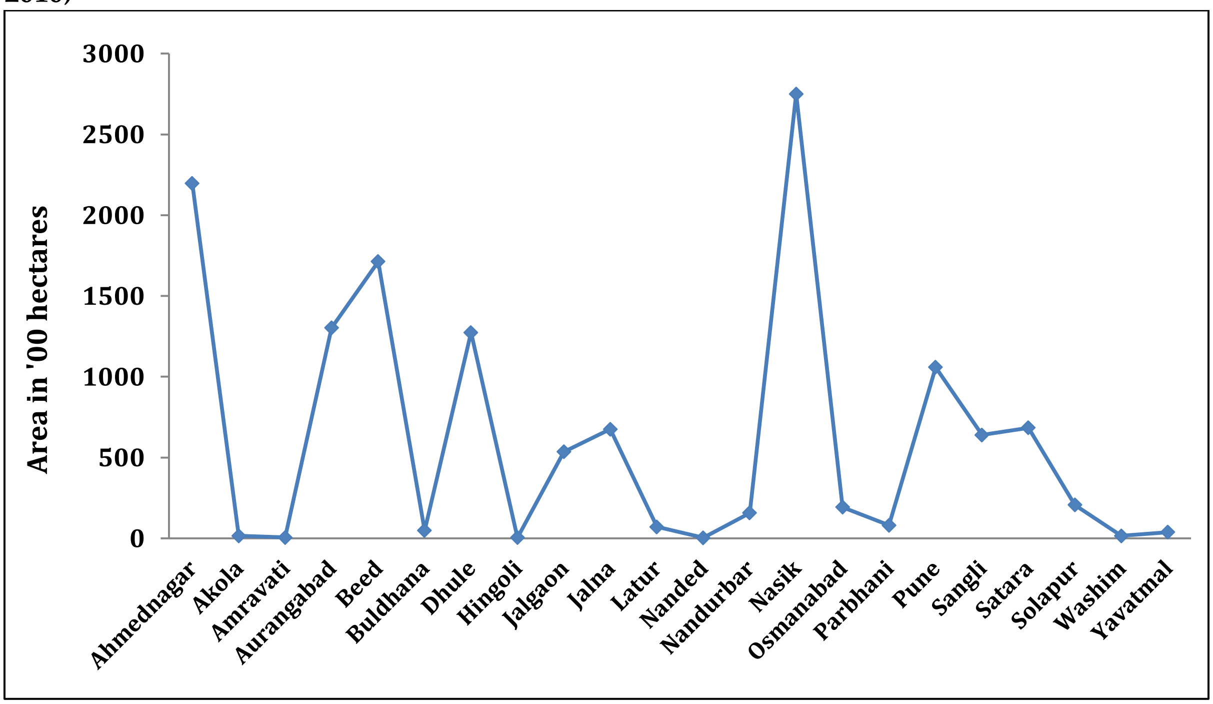
Figure 9: Decreasing trend in annual average area under cultivation of bajra in Maharashtra (2000-2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

Further, Nashik showed the highest area under cultivation of bajra among all the bajra growing districts in Maharashtra, which is illustrated in figure below.

Figure 10: District wise average annual area under bajra cultivation in Maharashtra (2000-2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

Further to identifying the crops and districts, the projections of temperature and rainfall for 2030s were compared with the optimum temperature and rainfall/ precipitation requirements of the selected crops. This helped understanding the impacts the crops would experience in given

future scenarios. Thus recommendations were provided in order to decrease the impacts on the crops due to exceeding the threshold levels of temperature and rainfall.
For e.g. the optimum temperature for growth of bajra is 27 - 30°C (Luo 2011) and rainfall requirement is more than 400 mm for the growth period (Fageria 1992). As Nashik is the district in which the area under bajra cultivation is the highest, the average temperature range in Nashik is about 17.5 – 31.7°C[26] and the average annual rainfall of the district is above 684 mm[27]. Based on the climate projections developed by UK Met Office for this project, the rainfall is expected to increase by 34% and temperatures by 1.5°C by 2030s. For better accuracy in developing the impacts, only the projections for 2030s have been considered in this analysis, as shown below.

Table 11: Threshold analysis for bajra in Nashik district

	Optimum requirement for bajra	Average Annual for Nashik	Projections for 2030s for Nashik
Temperature (in °C)	27 - 30	17.5 – 31.7	19 – 33.2
Rainfall (in mm)	400	684	916
Impacts	Crop losses due to extreme precipitation events		

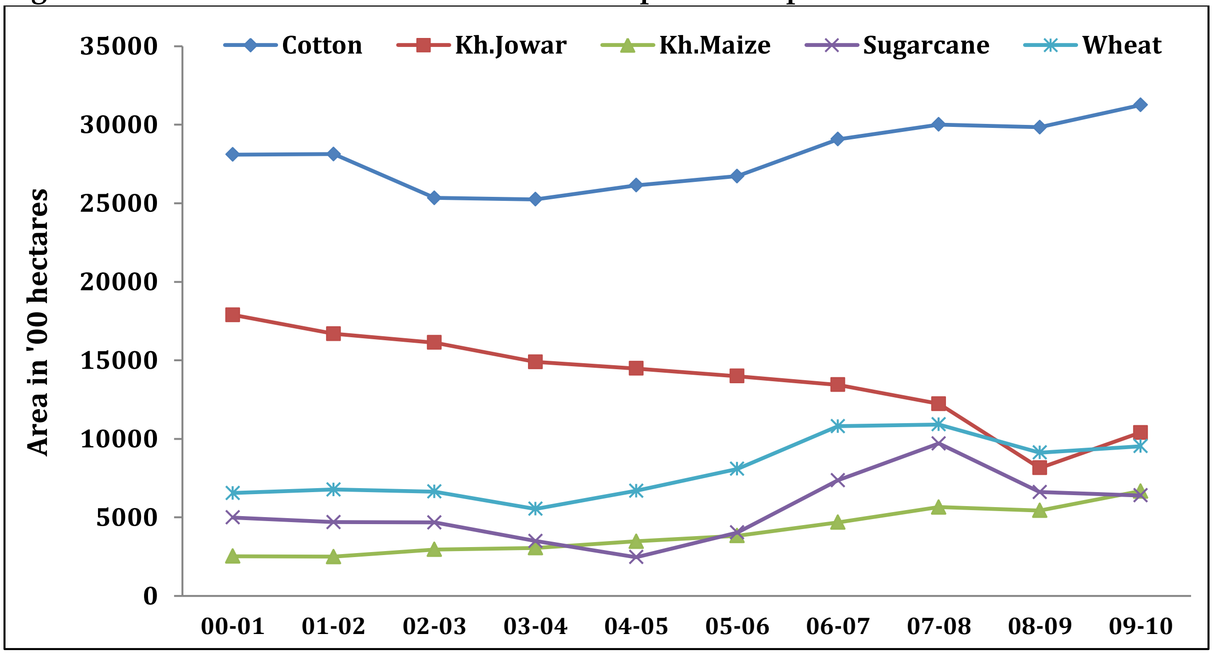
Thus it can be observed that the average annual rainfall for the district is much more than required and considering the projections, the crop is susceptible to failure due to excessive rainfall. In addition, it is projected that the increase in the rainfall would be in the form of increase in number of extreme rainfall days. Thus the crop is vulnerable to flash floods resulting in the huge losses. In order to secure the crop from severe climate events which can lead to crop loss, infrastructure and technologies should be provided such as shade nets.

10.2.2 Analysis

Apart from bajra, kharif jowar is the other crop which shows declining trend in area under cultivation, while sugarcane, cotton, wheat and kharif maize show an increasing trend as illustrated in Figure 11.

[26] According to Climatogical Normals (1961-1990), India Meteorological Department, Ministry of Earth Sciences, Government of India
[27] Ibid

Figure 11: Trend in area under cultivation of important crops in Maharashtra (2000-2010)

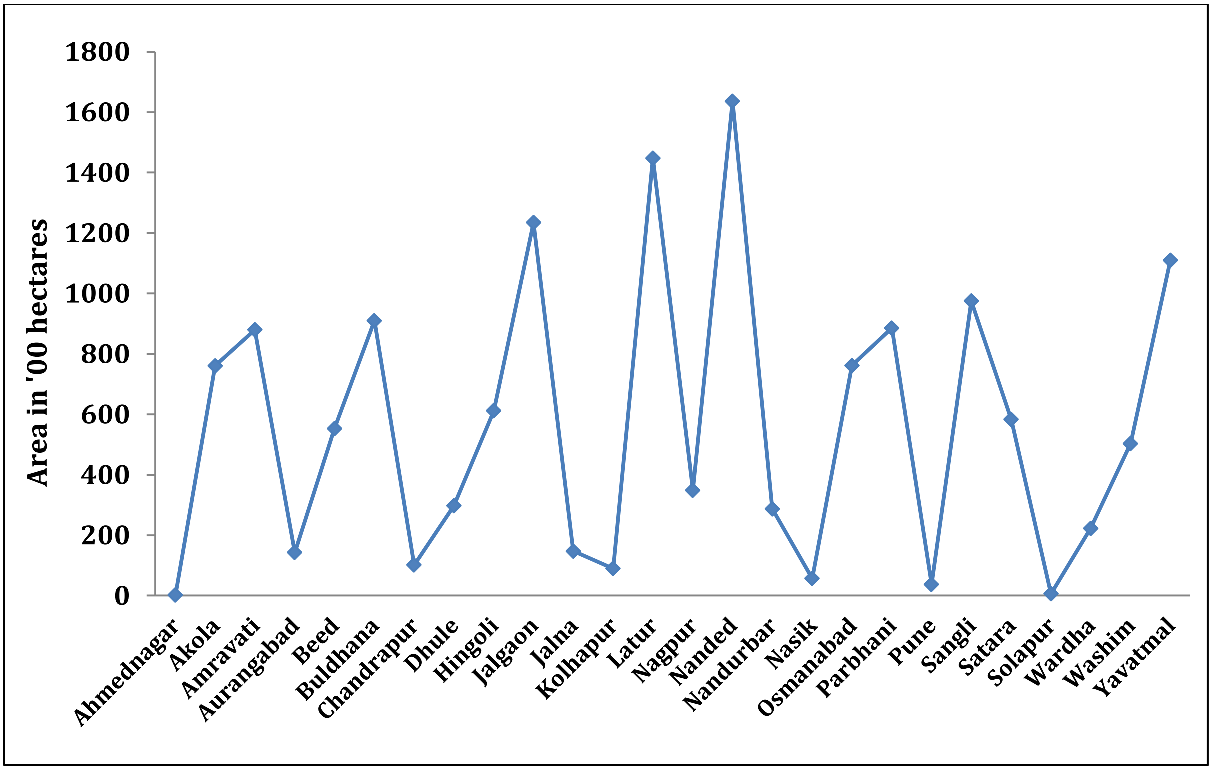


Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

Kharif Jowar

Now considering kharif jowar which shows a declining trend in area under cultivation, it has the largest area in Nanded district, as per the agriculture data acquired from Department of Agriculture, Government of Maharashtra which is represented below in Figure 12.

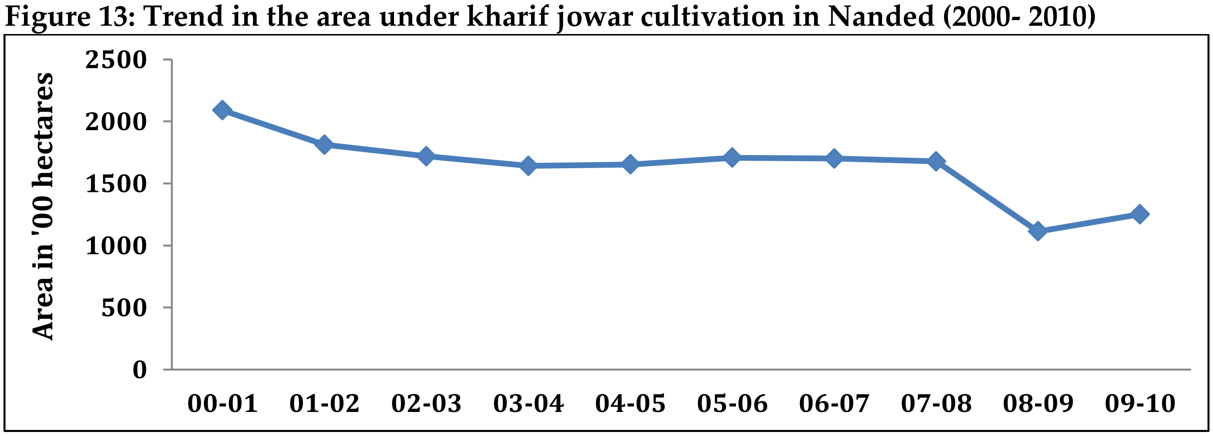
Figure 12: District wise annual average area under cultivation of kharif jowar in Maharashtra (2000-2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

Nanded also showed a decreasing trend in the area under cultivation of kharif jowar which is represented in the figure below.

Figure 13: Trend in the area under kharif jowar cultivation in Nanded (2000- 2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

The optimum temperature for growth of kharif jowar is 25 - 34°C (Luo 2011) and rainfall requirement is more than 450 – 650 mm for the growth period (FAO 1991). The average temperature of Nanded ranges from 19 to 34°C[28] and the average annual rainfall is around 950 mm[29]. Based on the climate projections, the rainfall in the district is expected to increase by 20% and temperatures by 1.5°C by 2030s. The threshold analysis for kharif jowar is illustrated in the table below.

Table 12: Threshold analysis for kharif jowar for Nanded district

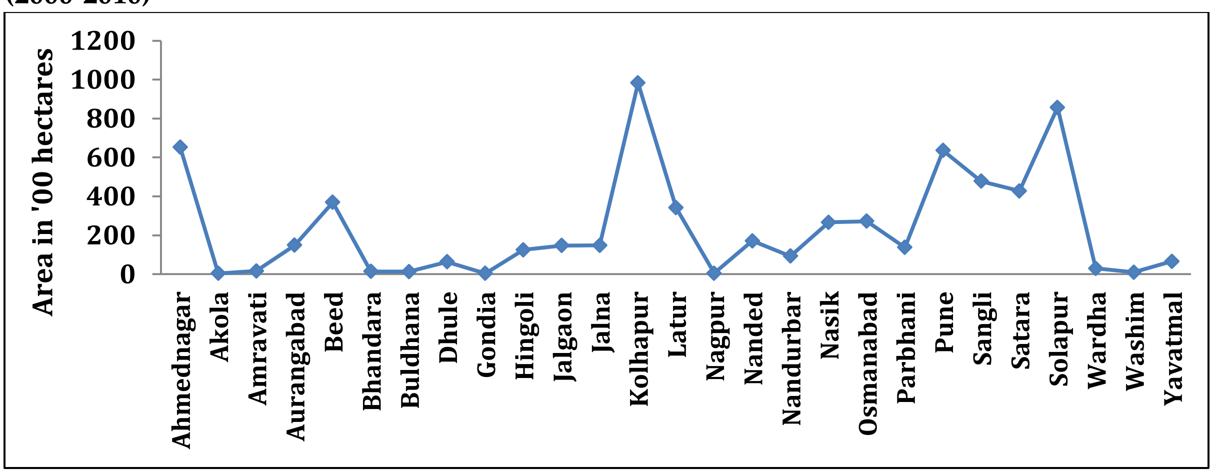
	Optimum requirement for kharif jowar	Average Annual for Nanded	Projections for 2030s for Nanded
Temperature (in °C)	25 - 34	19 - 34	20.5 – 35.5
Rainfall (in mm)	450 – 650	950	1140
Impacts	Crop losses due to extreme precipitation events		

Recommendations: Similar to bajra, kharif jowar also needs innovative technologies to protect it from high precipitation events.

Sugarcane

Sugarcane is one of the important cash crops of the state. Though area under sugarcane cultivation has been consistently increasing in the state as a whole, it has the highest area in Kolhapur district of Pune division. Please refer to the graph below to know the different district cultivating sugarcane and their respective areas under cultivation.

Figure 14: District wise annual average area under cultivation of sugarcane in Maharashtra (2000-2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

[28] According to Climatogical Normals (1961-1990), India Meteorological Department, Ministry of Earth Sciences, Government of India.
[29] According to Climatogical Normals (1961-1990), India Meteorological Department, Ministry of Earth Sciences, Government of India.

Crops such as sugarcane and cotton are unique to the state. This is because the area under cultivation of these crops has been increasing throughout the state which is guided by market forces. Though the threshold analysis is only carried out for Kolhapur district, the crop is growing in terms of area under cultivation among all the sugarcane growing districts of the state. Hence the impacts would be experienced by the sugarcane growing districts of Maharashtra. The projected increase in rainfall for Kolhapur is 15.30% and temperature is 1.3°C more than the average annual for the district. The threshold analysis for Kolhapur is presented below in Table 13.

Table 13: Threshold analysis for sugarcane in Kolhapur district

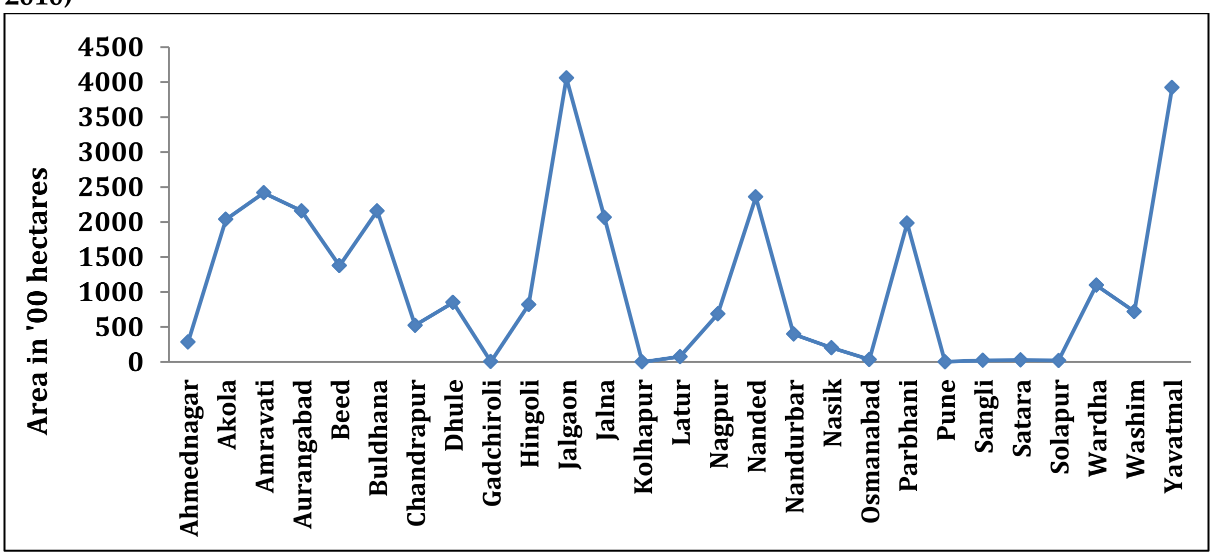
	Optimum requirement for sugarcane	Average Annual for Kolhapur	Projections for 2030s for Kolhapur
Temperature (in °C)	12 -38	19.4 – 31.5	20.7 – 32.8
Rainfall (in mm)	1200	1048.5	12.9
Impacts	Increased temperature would correspondingly increase the water requirement of the crop.		

Given the high requirement of the crop in comparison with the low rainfall, irrigation techniques need to be enhanced to meet the water requirement of the crop.

Cotton

Similar to sugarcane, cotton is extensively grown in Maharashtra except for Bhandara, Gondia and districts of Konkan division. The district which ranks first in terms of area under cultivation is Jalgaon, as shown in Figure 15.

Figure 15: District wise annual average area under cultivation of cotton in Maharashtra (2000-2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

As mentioned earlier, cotton occupies large area in the state barring a few districts and hence the impacts of climate variability would be seen across the state. The threshold analysis for Jalgaon which has the maximum area under cotton cultivation in state is presented below. For jalgaon the project increase in rainfall is around 34% and temperature is 1.6°C more than the average annual.

Table 14. Threshold analysis for cotton in Jalgaon district

	Optimum requirement for cotton	Average Annual in Jalgaon	Projections for 2030s for Jalgaon
Temperature (in °C)	25	20 - 35	21.6 – 36.6
Rainfall (in mm)	700 - 1300	750	1012.5
Impacts	Increased temperature would correspondingly increase the water requirement of the crop.		

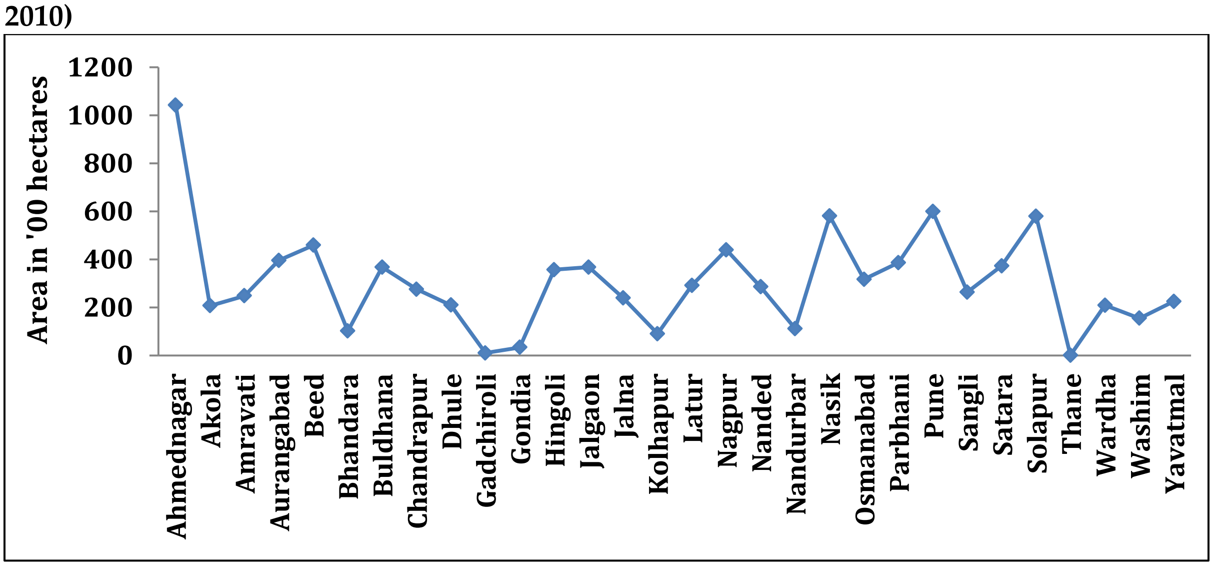
With increased temperature, irrigation techniques need to be enhanced to meet the water requirement of the crop.

Wheat

Wheat is a staple food in the state. Similar to cotton and sugarcane, it is grown in almost all districts districts except Raigad, Ratnagiri and Sindhudurg. The average production for wheat ranges from 100, from 100, 000 hectares in Gadchiroli to around 6000, 000 hectares in Pune. Ahmednagar has exceptionally large production of wheat with around 10,430, 000 hectares under wheat cultivation and cultivation and thus ranks first in the state for area under wheat cultivation. This is represented in the

Figure 16.

Figure 16: District wise annual average area under cultivation of wheat in Maharashtra (2000-2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

A detailed study conducted by Porter and Gawith (1999) monitored the different temperature requirements for different stages of wheat growth. It listed out the different temperature required for optimum growth and at which the sustenance of the crop is threatened. This includes base or cardinal temperature (Tbase), optimum (Topt1 and Topt2 indicating minimum and maximum), failure point (Tfp), lethal (Tlmin and Tl max). Crops grow ideally between the range of optimum temperature and at Tfp the grain yield fails to zero yield. The difference between cardinal and lethal Ts is that the recovery of function is possible with the range of cardinal Ts and irrecoverable once the lethal temperatures set in. The different threshold temperatures are listed in Table 15.

Table 15: Temperature thresholds (°C) for wheat

		Tlmin	Tlmax	Tbase	Topt	Tmax
Components	**Lethal Limits**	−17.2 (1.2)[a]	47.5 (0.5)[a]			
	Leaf initiation			−1.0 (1.1)	22.0 (0.4)	24.0 (1.0)
	Shoot growth			3.0 (0.4)	20.3 (0.3)	>20.9 (0.2)
	Root growth	−20		2.0[b]	<16.3[b] (3.7)	>25.0[b] (5.0)
Phenophases	**Sowing to emergence**			3.5 (1.1)	22.0 (1.6)	32.7 (0.9)
	Vernalization			−1.3 (1.5)	4.9 (1.1)	15.7 (2.6)
	Terminal spikelet			1.5 (1.5)	10.6 (1.3)	>20.0
	Antithesis			9.5 (0.1)	21.0 (1.7)	31
	Grain filling			9.2 (1.5)	20.7 (1.4)	35.4 (2.0)

Source: Porter and Gawith (1999) quoted from Luo Q. (2011)
Note:
a- Information in the brackets is standard error from a range of samples
b- Soil temperature

Thus considering these temperature thresholds and the climate change projections for wheat crop for the district of Ahmednagar, the impacts on this crop is assessed. The climate projections for Ahmednagar district is 1.5°C more than the climatological normal. This is well within the standard error limits for wheat except for couple of growth components and phenophases. In case of rainfall, it is projected to increase by almost 23% from the climatological normals. The threshold analysis and possible impacts are mentioned in the table below.

Table 16: Threshold analysis for wheat in Ahmednagar district

	Optimum requirement for wheat	Average Annual in Ahmednagar	Projections for 2030s for Ahmednagar
Temperature (in °C)	4.9 - 22	18 – 33	19.5 – 34.5
Rainfall (in mm)	450 – 650	575.4	707.7
Impacts	The temperature projections for 2030s are mainly outside the maximum temperature thresholds for different stages of wheat growth and hence it can impact the crop yield. The rainfall projections are observed to be suitable for growth of wheat crop.		

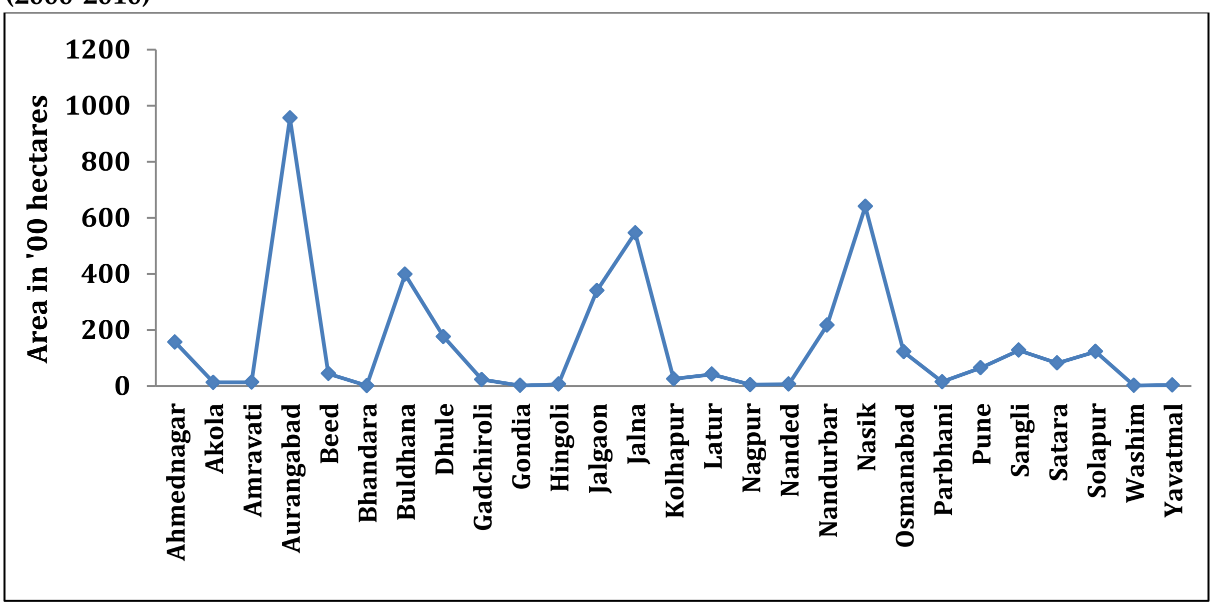
Recommendations: More heat tolerant varieties need to developed and disseminated in near future in order to avoid crop losses.

Kharif Maize

Maize has been gaining importance since the last decade, which is a major fodder supply in the state. This is one of the prime reasons for increase in the area under maize cultivation especially in kharif season. Yet the state has not explored the use of maize for bio-fuel.

In Maharashtra, except for coastal districts of Thane, Raigad, Ratngiri and Sindhudurg, maize is grown in all the remaining states, even though on a very small scale. The largest maize producing districts are Aurangabad, followed by Nashik and Jalna. Thus the threshold analysis would be carried out for Aurangabad district.

Figure 17: District wise annual average area under cultivation of kharif maize in Maharashtra (2000-2010)



Source: Primary data from Commisionerate of Agriculture, Department of Agriculture, Government of Maharashtra.

According to the climate projections, the temperature in Aurangabad is expected to increase by approximately 1.5°C and rainfall by approximately 25%. Hence by comparing the optimum temperature required for maize, the average annual for the district and the projections; the threshold analysis for maize for the district of Aurangabad is as given below.

Table 17: Threshold analysis for kharif maize in Aurangabad district

	Optimum requirement of maize	Average Annual of Aurangabad	Projections for 2030s for Aurangabad
Temperature (in °C)	15 - 45[30]	19.5 - 33	21 – 34.5
Rainfall (in mm)	500.-800[31]	756.6	975.7
Impacts	The temperature are within the range suitable for the growth of kharif maize and the rainfall too will be suitable with a little increase in the total precipitation		

Recommendations: The current climate is suitable for the varieties being cultivated. Though there is no major change in the rainfall, water efficient irrigation techniques can help in maximum productivity of the crop.

10.2.3 Conclusions

While some crops show a decreasing trend and other crops increasing, different input and seed technologies need to be promoted to enable the crop to adjust the changing environment. Few of the existing technologies that need to implemented on a mass scale are

1. Heat resistant varieties in selected crops
2. Water efficient irrigation technologies
3. Infrastructural technologies such as shade nets

Regardless of increasing rainfall in the near future, policy interventions need to be strengthened to encourage usage of water efficient irrigation techniques. To supplement this, awareness needs to be generated towards sensitizing the agriculture communities about the benefits of such irrigation techniques. In addition to this, innovative methods need to be developed which can safeguard the crops against extreme rainfall events, which pose a major threat to the entire agrarian system of the state.

[30] http://www.fao.org/nr/water/cropinfo_maize.html
[31] http://www.fao.org/docrep/u3160e/u3160e04.htm

10.3 Climate Change impacts on select Food Crops

Inter-annual, intra-seasonal, monthly and daily distribution of climate variables (primarily temperature, precipitation and humidity) play a fundamental role in most of the physical, physiological, chemical and biological processes that drive productivity in agriculture. Agriculture is particularly vulnerable to climate change. A number of environmental, social and economic factors contribute to the 'differential vulnerability' of diverse farming systems and the communities involved in the country. Rainfed areas, in particular, have complex cropping systems operating under fragile ecological conditions. While in the long run climate change is likely to exacerbate current stresses and increase the vulnerability of food production and livelihoods of farming communities, one cannot ignore the impacts in the short run caused by greater climatic variability and more frequent occurrence (or increased severity) of extreme weather events. Climate change is likely to significantly alter the dynamics of extreme events - such as tropical cyclones, associated storm surges, and extreme rainfall events - possibly increasing their frequency and intensity. Low lying regions along the coast, including small islands, will face the highest exposure to rising sea levels, which will increase the risk of floods bringing more cultivable area under the risk of submergence and degradation.

Many other existing factors contribute to increasing the vulnerability of agricultural systems to climate variability, climate change and extreme weather events. Poverty levels and the population density are already high - important factors contributing towards high sensitivity to climate change. Multiple stresses on natural resources such as soil erosion, salinization of irrigated lands, degradation of pastures, water pollution and overexploitation of forest stocks contribute to low resilience in farming systems. Since most of agricultural production takes place in rural areas and engages people from the marginalized section of the society, poverty and hunger are found to be concentrated in these regions despite the fact that they are the locus of food production.

The low coping capacity of farmers is a significant factor contributing to high vulnerability of the sector to both climatic and non-climatic stresses. For instance, many farmers often bypass institutional or formal financial mechanisms and resort to informal credit sources, despite high rates of interest in conditions of declining farm incomes. Agricultural markets and food supply chains are mainly unorganized and dominated by intermediaries who exploit the small farmers making up the largest proportion of producers. Post-harvest losses occur at a huge scale all through the supply chain due to inadequate storage and transport infrastructure, and wide-spread lack of market information and intelligence among the farmers. Coping responses of farmers to shocks such as droughts are often of the distress type such as selling off of farm assets like livestock or land. Although there are mechanisms in the country that operate to provide farmers with adequate information access on weather and crop management, they often operate on a delayed mode, lack feedback loops, and often function in isolation. In sum, therefore, the combination of high vulnerability, low adaptive capacity and high economic importance makes building resilience in agriculture and allied sectors a challenging but crucial task.

Impacts on crops are likely due to;

1. **Temperature changes** - If the temperature increases are higher, western India may show some negative impact on productivity due to reduced crop durations. Local weather changes can cause disruption of flowering / fruiting cycles & change in pest profile. Simulations using dynamic crop models indicate a decrease in yield of crops as temperature increases. In the agriculture sector the major impacts of climate change will be on rain fed or un-irrigated crops. In the past fifty years, there have been around 15 major droughts, due which the productivity of rain-fed crops in drought years was adversely affected. For example, by the end of this century short periods of hot temperatures that are found in some regions in the current climate will be found over a wider area. If these occur at flowering time, then the harvest of annual crops, such as groundnut and wheat, can be seriously reduced.

2. **Water availability** - Projected climate change resulting in warming, precipitation patterns, increased frequency of extreme events, sea level rise and melting of glaciers will undoubtedly affect the water balance and water quality. Since most of the cultivated land is rainfed and agricultural success heavily depends on the annual monsoons, agriculture performance and well-being of the Indian farmer is highly climate sensitive. Changes in rainfall patterns causing water shortages in some regions, combined with thermal stress, can adversely affect crops like wheat and rice.

3. **CO_2 concentrations** - In the short run, increase in CO_2 concentrations might contribute to an increase in yields which to some extent gets negated by increases in temperatures. But as the temperatures increase further, the yield losses are predicted to be further high. Most of the simulation studies on different crops in different regions of India have shown a decrease in the yield of crops with an increase in the temperature.

4. **Moisture changes** - Temperature and moisture have an important role in determining the quality of the produce. It is likely that climatic changes will have significant effect on the quality of cotton, fruits, vegetables, tea, coffee, aromatic & medicinal plants etc. The nutritional quality of cereals & pulses may also be moderately affected by this change in temperature.

5. **Pests and pathogens** - It is estimated that, damage to crops by pests, pathogens and weeds, contribute to an estimated 30% losses in production at present. The change in climate may bring about a change in the population dynamics, growth and distribution, and crop interactions of insects and pests, thereby aggravating the existing situation. The temperature increases associated with climate change could impact pest insect populations in several complex ways such as, extension of geographical range, increased over-wintering, changes in population growth rate, increased number of generations,

extension of development season, changes in crop-pest synchrony, changes in inter-specific interactions, increased risk of invasions by migrant pests, and introduction of alternative hosts and over-wintering hosts. Being poikilotherm, insects respond rapidly to climatic variations. They have very high degree of adaptability and may evolve very fast in response to a changing climate. Recently it was observed that some insects have contracted their distribution range due to increase in temperature and reaching to extinction. This is more likely to be a case in the tropics which may increase the probability of secondary pest outbreak in these areas. This may also affect predator-prey relationship and lead to temporal isolation between them. Further, temperature and rainfall pattern may upset insect prototype, radically, influencing migrant population dynamics. Drought may result in various physiological changes in plants that can increase the susceptibility to herbivorous insects. Due to changes in climatic patterns, the incidence of pathogens affecting various crop plants has also been affected. There is continuous evolution in the pathogenic races of fungi and bacteria due to selection pressure and climate change.

The impacts of such changes in the climate on agriculture may be manifested in different forms, be it an increase in pests, stunted growth of crops or changes in the crop growth cycle like early or late flowering, depending on the location. Table 18 presents the potential impact that some of the key climate risks may have on important crops in Maharashtra.

Table 18: Key climate risks and potential impacts on key crops

Key Climate Risks	Potential impacts on Key crops
Increase in maximum temperature	- Sterility in rice pollen if during anthesis; Decrease in pollen germination; 10% reduction in rice grain yield per °C temp rise beyond 1°C - Dessication of seedlings - Accelerated plant maturity and reduced grain filling in food grains
Increase in minimum temperature	Negative impact of warmer nights on rice yield; Negative impact on rabi wheat crop if Jan temp rises (as projected by INCCA 4x4 assessment)
Increase in average rainfall	- Positive impact on rabi crop - May also have positive impact on kharif crop if rainfall distribution is timely
Decrease in June rainfall	- Untimely dry spells will damage rice crop - Late onset of monsoon can reduce cotton yield (from 15-20 quintals/acre to 10 quintals per acre)* - Difficult crop establishment
Increase in Aug-Oct rainfall (significant increase in Aug rainfall observed in most districts and in Oct rainfall in many districts of Maharashtra over 1901-2006 (IMD 2012))	- Increasing rainfall in post-monsoon increases pest infestations. For example- black mould in jowar, and heliothis sp. in cotton and red gram - Heavy rains during or after harvest can lead to incompletely dried crops before storage, causing fungus during storage period
Increase in Dry days	- Impact on water availability for fodder and livestock in south Madhya Maharashtra and Marathwada

Key Climate Risks	Potential impacts on Key crops
	- Dry conditions during grain filling and maturity can increase cracked grains, which are susceptible to fungus In end stages, can lead to poor grain filling
Increase in runoff (e.g. as projected over Vidarbha)	- State may not benefit from the projected increase in rainfall and rainwater is lost as runoff and cannot be stored (esp. for the dry season/ rabi crop)
Exacerbation of soil erosion (especially on steep slopes in Nandurbar and Konkan	- Exacerbation of soil erosion (compounded by deforestation) and esp. before the sowing season, when the soil is not held by any plant cover - Loss of soil productivity - Siltation of check dams
Increase in humidity	- Bacterial disease on pomegranate crop (e.g. in Solapur, Sangli, Satara in 2005-07) - Livestock infections and diseases (e.g. alternating drought and heavy rainfall cycles foster midge and mosquito vectors) - Complex changes in incidence of pests / pathogens, e.g. though temp rise may reduce incidence of certain pests /pathogens (e.g. rice gundhi bug), but simultaneous increase in temperature and rainfall will create favourable conditions for many pathogens (e.g. powdery mildew on grape)

Sources include: ICRISAT (2013, 2008), Aggarwal (2011), ICRIER (2012), FAO (2012), Cooper et al (2009), Shankar et al (2011), Jat et al (2012), Ericksen et al (2011), and expert consultations at the KVK/ NICRA researchers

The following are some examples of select crops and possible effects of a changing climate on them. Table 19 provides a snapshot of impacts due to increase in carbon dioxide concentrations and increase in temperature with possible future projections of crop performance in Maharashtra and neighbouring regions from peer- reviewed literature.

Table 19: Potential impacts and future projections for key crops from the literature

Crop	Impact due to increased CO_2 concentration	Temperature	Future Projections
Rice	Increases in CO_2 concentration up to 700 ppm resulted in average yield increase of 30.73% by ORYZA1 model (Krishnan et al., 2007)	Increase in temperature from 1 to 4 °C resulted in reduction in yield of Rice from 0 to 49% (Singh et al., 2009)	By the 2030's rain fed rice yields in the Western Ghats will range from -35% to +35% (INCCA 4X4 Assessment, 2010)
Sorghum	An increase in 50 ppm CO2 increases yields by only 0.5%. The beneficial effect of 700 ppm CO2 was nullified by an increase of only 0.9◦C in temperature (Chatterjee, 1998)	A 1°C and 2.3°C rise in temperature resulted in 6.3% and 17.5% decline in sorghum yield in Bijapur (A2a scenario) (Boomiraj	Sorghum yield declined by 4.5, 11.2, 18.7% in 2020, 2050 and 2080 respectively (Geethalakshmi et al., 2009)

		et al., 2011)	
Cotton	Cotton under elevated carbon dioxide level of 650 ppm and temperature of 40 degree centigrade was found optimum, leading to improved productivity (Vision 2025, ICAR)	A temperature increase of 1.85°C in the A1B scenario will result in no significant change in yield in central India. However, a 3.2 rise in temperature would lead to a 268 Kg/ha decline in yield in Central India (Hebbar et al., 2013)	
Soybean	Free air CO2 enrichment(FACE) experiments on soybean show an almost 15% increase in yield due to elevation of carbon dioxide concentration to 550 ppm (Singh et al., 2009)	Increase in temperature from 1 to 4 °C resulted in reduction in yield of 11% to 36% (Singh et al., 2009)	The potential yield of soybean will decline by 14% to 17% by the 2030s in the A1B scenario in Madhya Pradesh (Indo- UK research programme, 2012)

10.3.1 Crop modelling- Rice as an example

Multiple iterations of stakeholder consultations across several tiers of government, including local stakeholders have revealed several impacts on the agriculture sector, which have been perceived as impacts due to the variability and change in the climate. The impacts on the agriculture sector are not just localized to the crop performance or the farmer alone but have far reaching impacts that traverse to much larger scales (Figure 18). The approach that has been used in this study attempts to encapsulate the variety of impacts that are observed across different scales.

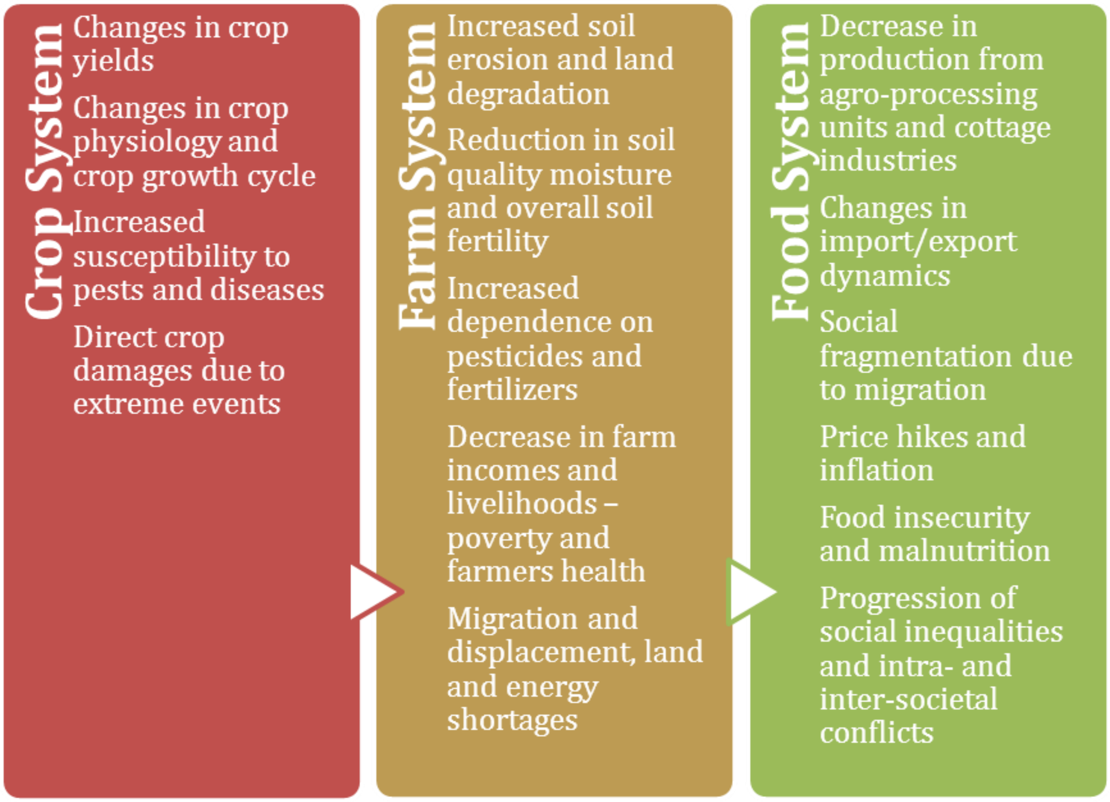


Figure 18 Progression of impacts across scales.

10.3.1.1 Methodological Approach and results

The approach used in defining the assessment has borrowed concepts from several novel approaches that look at the complex system of agriculture from different lenses. Figure 5 outlines the three broad scales of assessment. While these are stand-alone approaches of assessment, the present approach draws a few components from each of these approaches to determine and address the most important needs for agricultural assessment for Maharashtra.

The progression of the scale of assessment starts from the largest scale of the food system and progresses to the next level of the farming system and then in concludes at the crop system level.

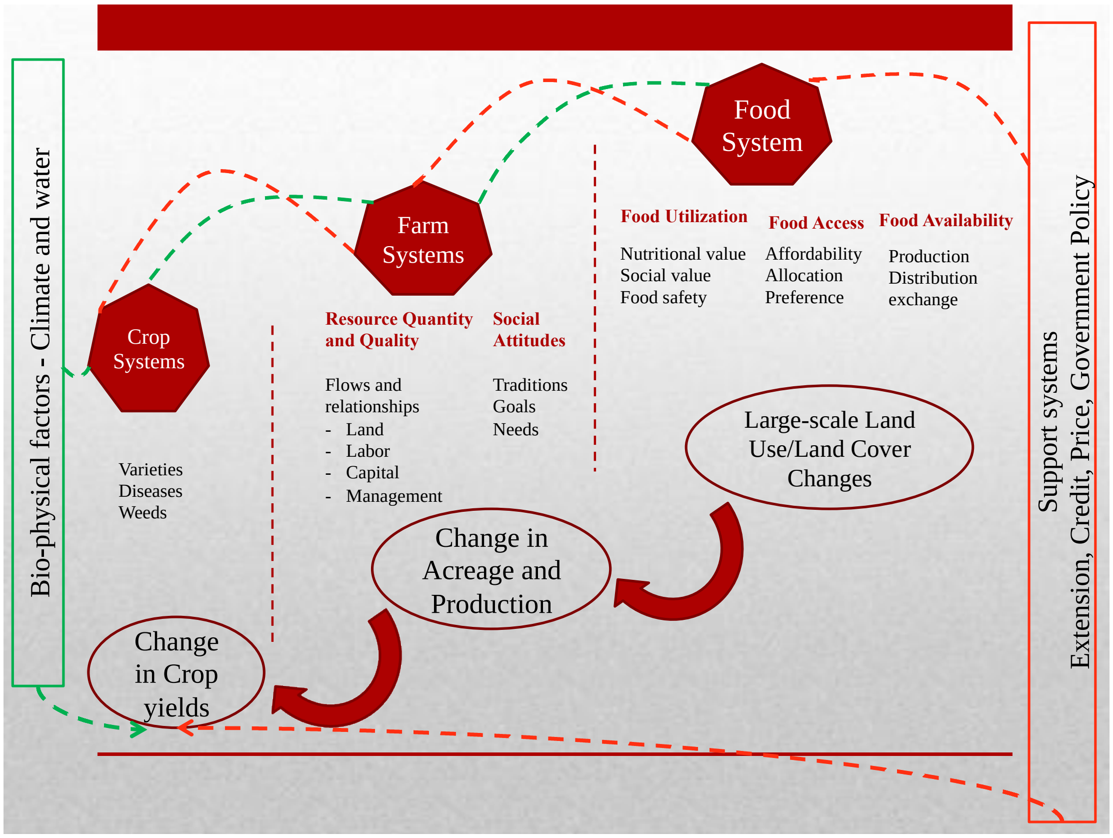


Figure 19: Interlinkages between the three approaches

Food systems approach: Food systems have usually been conceived of as a complete set of activities, which include all steps from production to consumption. However, the complex issue of food security does not conform solely to the production and consumption of food but is also determined by the related environmental, social, political and economic factors. These determinants encompass the components of availability, access and utilization. These determinants or drivers are therefore are representative of a broader understanding if the food systems. A broader definition of food systems therefore includes (Ericksen, 2007)

- The interactions between and within bio-geophysical and human environments, which determine a set of activities
- The activities themselves (from production through to consumption);
- Outcomes of the activities (contributions to food security, environmental security, and social welfare) and
- Other determinants of food security

From the food systems approach, the drivers of food security were selected as part of the approach that leads to an understanding of land use changes derived from a combination of biophysical changes and demographic changes. Based on the changes in land use, the areas where maximum conversion from agricultural land to scrub lands occurs is identified. It is this identified areas where further assessments at the farming system and crop system level are undertaken.

A predictive modeling assessment of changes in land use and land cover was undertaken with several independent variables that included (i) social agents of change namely proximity to road, and proximity to settlement, (ii) topographic agents of change namely proximity to water, elevation, slope, aspect and dependent variables of the change in the forest cover and land use in past decades. Population pressures have largely driven the trends in the predictions. In addition to this, the accessibility variables that are development driven were given more importance than the topographical ones and socio-economic land use practice and conversion of land to permanent agriculture have also been considered as they play an important role in changing landscape as underlying driving forces of forest cover changes. These assessments were done for the baseline years 1998, 2005 and 2012 as well as for the future for the years 2030, 2050 and 2070.

Results: From the land use land cover assessments looking at the progression of land cover changes in the baseline period from 1998, 2005 and 2012 to future predictions for 2030, 2050 and 2070, it is clear that the loss of agricultural land is the most prominent.

Agricultural land is observed to covert more and more to open land in the baseline period from 1998-2012. These changes area more localized in the Northeastern reaches of Maharashtra. However, in the predictions for 2030s and beyond, the changes from agricultural lands to open lands and settlements is localized in the North Konkan Zone of Maharashtra. This is fairly cogent as even at present areas, in and around Thane and Raigad are coming up with new ambitious, large-scale development projects that are thereby expanding the spread of the settlements slowly but steadily. Keeping in mind that at present this area of agro-climatic zone is one of the most productive regions in Maharashtra, the and would definitely face impacts of a rapid pace of development, it becomes vital to study the additional impacts climate change on the farming systems in this region.

Farming systems approach: Based on the farming systems approach, this component aims to understand the present change in acreage and productivity for major crops in the region. The North Konkan Zone which is identified under the food systems approach to be the area where maximum agricultural land would be converted to open land in the future, falls in the Konkan division which experiences the maximum amount of rainfall in the State. According the Agro-climatic zones and characteristics defined by the Department of Agriculture, Rice is the major crop grown in the ACZ apart from vegetables and pulses. Therefore the crop assessment for potential yield of rice in a climate change scenario was undertaken up as an example

Grown over an area of 14.99 lakh hectares with an annual rough rice production of 32.37 lakh tones, in Maharashtra, rice is the second important crop of the people after Jowar. The average productivity of the state is 2.01 t/ha. Over the decades, the area, production and yield of rice has consistently increased in Maharashtra, thereby establishing it as one of the most important crops in the state which had held its position in spite of the propagation of more lucrative crops like cotton and sugarcane. The Konkan region is where rice is traditionally grown.

Rice is the second important crop after Jowar in Maharashtra State. The total area under rice crop remained stable around 15 lakh ha and production around 24 lakh tones with 1.7 to 1.9 t/ha productivity during last 15 years in the state. The Agricultural Universities in the state has released total 54 high yielding varieties, 4 rice hybrids and developed improved package of practices for cultivation of rice crop since 1970.

Table 20: Performance of rice in Maharashtra across the decades

	1960-61 to 1969-70	**1970-71 to 1979-80**	**1980-81 to 1989-90**	**1990-91 to 1999-2009**
Area ('000' ha)	1334.70	1358.0	1490.50	1534.33
Production ('000' mt)	1314.70	1533.50	2173.40	2424.00
Productivity (t\ha)	0.99	1.13	1.46	1.94

Moreover, specifically in the Konkan division and the North Konkan districts of Raigad, the production of rice has also seen an increase in past years.

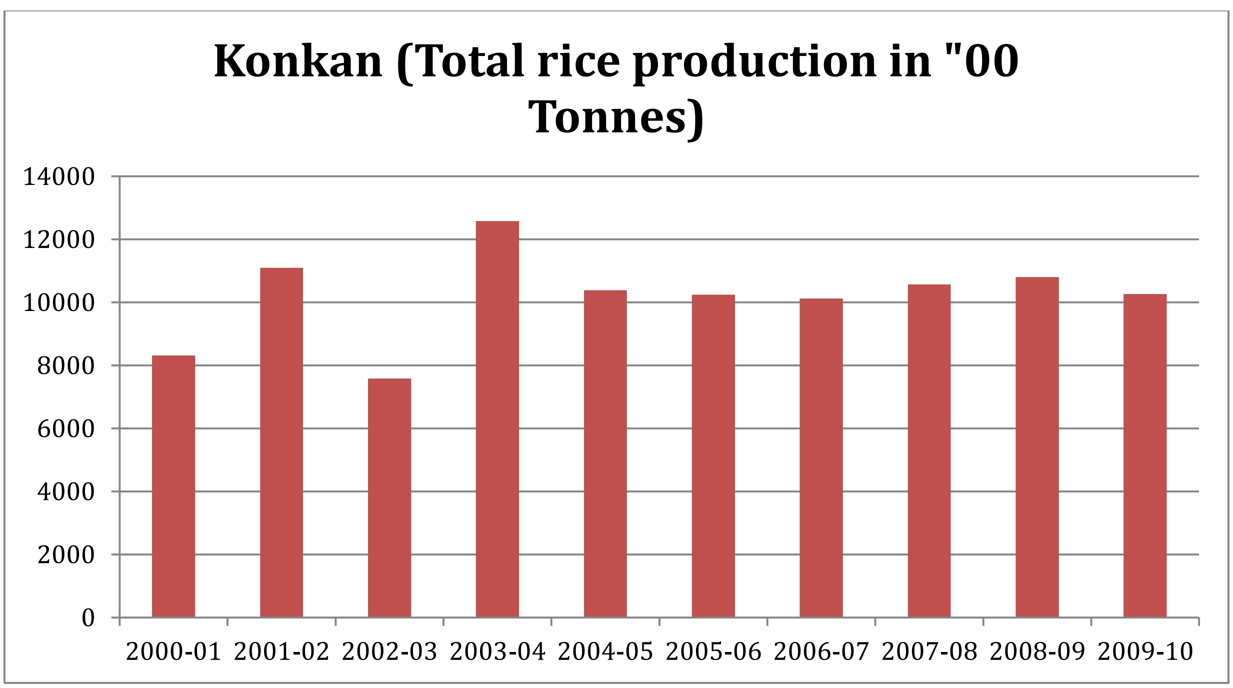


Figure 20: Total rice production (Kharif + Summer rice) trend in the Konkan division (Source: Data from Department of Agriculture, Maharashtra)

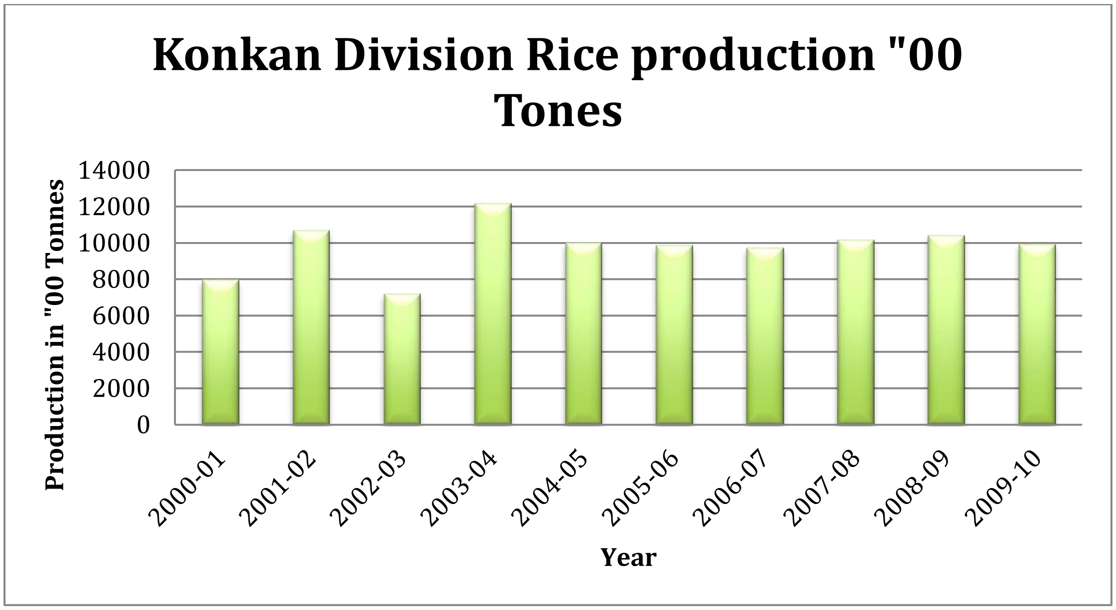


Figure 21: Production for Kharif rice crop in all of Konkan division (Source: Data from Department of Agriculture, Maharashtra)

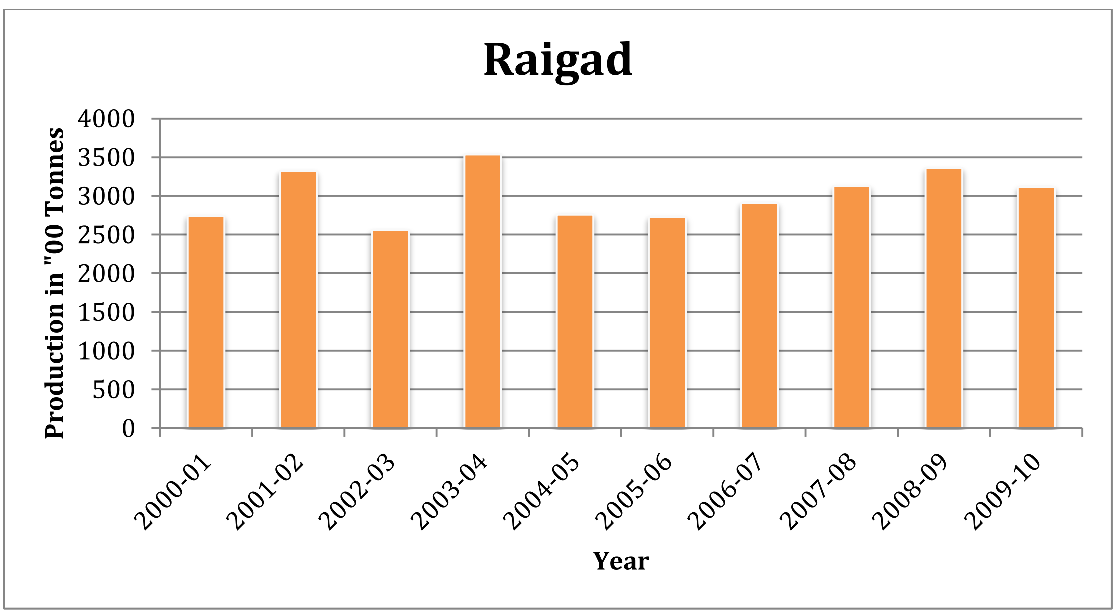


Figure 22: Production trend in Raigad district (Source: Data from Department of Agriculture, Maharashtra)

Thus in the Konkan farming system, Rice is the most important crop and would be undertaken for assessment in the crop system approach.

Crop level assessment: On the basis of the preceding steps, rice (paddy) has been selected as the example of a crop that would be studied for changes in potential yield in a future climate scenario (A1B). For such assessments crop growth models or cropping system models, that require detailed input datasets are used. Cropping system models can be run for specific cultivars or crop varieties. In the case of Maharashtra, the impacts of the changing climate on the rice variety Jaya was assessed. In this case, the crop growth model used is the Ceres-Rice model under the DSSAT shell. The DSSAT package has been used to assess the impact of climate change on agriculture. The DSSAT package has been in use and has been improvised upon for over 15 years. It incorporates models of 16 different crops in its cropping system model (CSM). The model for rice, which has been incorporated into this module, is Ceres-Rice. The Ceres-Rice model has been used by researchers in India as well as abroad for crop simulation in various studies. Although it has been calibrated and validated over several studies it has not been evaluated as much. Mostly, the Ceres-Rice model has been evaluated in studies conducted in tropical and sub-tropical locations in Asia. Along with the cropping system model, DSSAT also has a weather module which can be used to input weather data into the system or also to generate weather data for specific time periods. DSSAT also has a soil module. It reads in soil parameters of the land unit and modifies them based on tillage, long-term changes in soil carbon or other such field changes.

Scale of assessment: The assessment was done for the rice variety – JAYA at the field level for Karjat in Raigad district.

Model description

The CERES rice and wheat models simulate the growth, development and yield of a component crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, C and N that take place under the cropping system over time. The models consider the effects of weather, genetics, soil water, soil C and N, and management in single or multiple seasons and in crop rotations at any location where minimum inputs are provided.

Growth

The models predict daily photosynthesis using the radiation-use efficiency approach as a function of daily irradiance for a full canopy, which is then multiplied by factors ranging from 0 to 1 for light interception, temperature, leaf N status, and water deficit. There are additional adjustments for CO2 concentration, specific leaf weight, row spacing, and cultivar (Ritchie et al. 1998). Growth of new tissues depends on daily available carbohydrate and partitioning to different tissues as a function of phenological stage and modified by water deficit and N deficiency. Leaf area expansion depends on leaf appearance rate, photosynthesis and specific leaf area. Leaf area expansion is more sensitive to temperature, water deficit, and N stress. During seed fill, N is mobilized from vegetative tissues. As a result, vegetative tissue N concentration declines and this in turn lowers photosynthesis and causes leaf senescence to increase. Protein and carbohydrate mobilized from vegetative tissue contribute to seed growth while photosynthesis declines (Godwin and Singh 1998). Cultivar differences in yield components, tillering, and temperature tolerance are captured by the model using a suite of coefficients specific to a cultivar.

Water balance

The soil water balance model developed for CERES-Wheat has been adapted by all of the DSSAT v3.5 crop models (Ritchie 1998). This one-dimensional model computes the daily changes in soil water content by soil layer due to infiltration of rainfall and irrigation, vertical drainage, unsaturated flow, soil evaporation, plant transpiration, and root water uptake processes. The soil has parameters that describe its surface conditions and layer-by-layer soil water holding and conductivity characteristics. The model uses a "tipping bucket" approach for computing soil water drainage when a layer's water content is above a drained upper limit parameter. Drainage of water through the profile is first calculated based on an overall soil drainage parameter assumed to be constant with depth. The amount of water passing through any layer is then compared with the saturated hydraulic conductivity of that layer. If the saturated hydraulic conductivity of any layer is less than computed vertical drainage through that layer, actual drainage is limited to the conductivity value, and water accumulates above that layer. This feature allows the model to simulate poorly drained soils and perched water tables.

CERES-Rice adds to this the simulated effect of the presence of a bund. Floodwater depth, runoff (when floodwater depth exceeds bund height) and evaporation from floodwater are simulated. The model also simulates the effect of changes in percolation rate and bulk density associated with puddling and the reversion to a non-puddled state.

Soil organic matter and nitrogen dynamics

DSSAT has two options to simulate the soil organic matter (SOM) and N balance. First, the original SOM model in DSSAT v3.5 (Godwin and Jones 1991; Godwin and Singh 1998) and second, the SOM module developed by Gijsman et al. (2002), based on the CENTURY model (Parton et al. 1988, 1994). The CENTURY-based module (i) divides the SOM into more fractions, each of which has a variable C:N ratio and can mineralize or immobilize nutrients, (ii) has a residue layer on top of the soil, and (iii) considers a texture dependent decomposition rate. In addition, the N module simulates hydrolysis of urea, nitrification, ammonia volatilization, N leaching, denitrification, algal activity and floodwater pH changes, plant N uptake, grain N dynamics, and plant N stress indices (Figure 1). The floodwater N chemistry component of the model (Godwin and Singh 1991, 1998) uses an hourly time step to calculate rapid N transformations and to update soil-floodwater-atmosphere equilibria. The water and N submodels can simulate water and N balances under fully irrigated flooded conditions, rainfed conditions where rice is alternately inundated and dry, and fully upland conditions where the soil is never flooded (Singh 1994).

Input data

The DSSAT simulation model has several input data requirements. They can broadly be categorized under Weather, Soil and Crop Management (Table 7).

Weather: For a climate impact assessment, two sets of weather data are required for climate parameters, which include, minimum temperature, maximum temperature, rainfall and solar radiation. One set is the baseline dataset using which the model is calibrated and validated and the other sets are for the climate scenarios for which future assessments are to be made. Ensemble models for the regional climate model PRECIS were used to generate the climate scenarios at a 25km x 25 km resolution for the station Karjat in Raigad district.

Table 21 Input requirements for crop growth model

Soil	Crop management	Crop growth variables	Genetic coefficients (for rice)
Soil Classification	Cultivar name	Panicle initiation day	P1: degree days from emergence to end of juvenile phase
Colour	Planting date	Anthesis day	P2: Photoperiod sensitivity
Texture	Planting method	Physiological maturity day	P5: degree days from silking to physiological maturity/ linear fill to matrurity (in case of wheat and barley)
Percentage slope	Planting distribution	Yield at harvest maturity	P1D: photoperiod sensitivity coefficient
Drainage	Plant population at seeding	Unit weight at maturity	P1V: vernalization sensitivity coefficient
Runoff potential	Plant population at emergence	Number at maturity	G1: Kernal number per unit stem + spike weight at anthesis
Fertility factor	Row spacing	Pod/panicle	G2: Potential kernel number (maize)/growth rate (wheat and barley)
Percentage of clay, silt and stone at several depths	Planting depth	Leaf area index, maximum	G3: tiller death coefficient
Percentage organic carbon content	Row direction	Tops weight at antithesis	G5: Potential kernel growth rate
Percentage nitrogen content		Tops number at maturity	PHINT: thermal time between the appearance of leaf tips
Cation exchange capacity		Tops weight at maturity	
pH in water		By-product produced (stalk) at maturity	

Soil	Crop management	Crop growth variables	Genetic coefficients (for rice)
Bulk density		Harvest index at maturity	
Albedo		Leaf number per stem at maturity	
Runoff curve number			
Drainage rate			

Baseline: Model simulated baseline data was used for the period 1990-2000 for the baseline assessment. The model could not use IMD datasets as all the required input parameters (Solar radiation) were not available at a 25 Km x 25 Km resolution. Therefore, a choice was made to use NCEP reanalysis data. However the results obtained from the NCEP observational datasets were not comparable with the model generated results as the physics and the assumption in the two models are entirely different. Hence, in order maintain consistency in results, the model simulated baseline dataset was used.

Climate Scenarios: For the future scenarios from the year 2020 to 2080, the ensemble mean from 4 models using the A1B scenario from the PRECIS RCM at a resolution of 25 km x 25 km was used.

Soil: The data on soil parameters such as texture, color, cation exchange capacity, soil composition, water-holding characteristics, soil pH, and depths of three soil layers were obtained from the Maharashtra soil series published by NBSSLUP, Nagpur.

Crop management data: The field experimental data was obtained the Karjat research station in Raigad district as well as field level consultation with farmers who grow the rice variety Jaya. This field site has been taken as the representative.

The genetic coefficients were inbuilt in the Ceres-rice model was used for Jaya. The model could not be calibrated or validated due to lack of adequate data. Therefore the results obtained are indicative in nature.

Limitations: The limitations of this approach was the lack of actual field experimental data in the various input categories to allow for simulations other than those for potential yield assessments. For the same reason assessments of pest incidences were not included.

Results

The DSSAT cropping system model gave results in the terms of yield in Kg/ha. For the baseline the average yield was found to be 2736.8 Kg/ha

Projected yield changes: In keeping with the baseline studies of increasing trend of rice cultivation in the Konkan region in Maharashtra, and the projected percentage increase in the amount of rainfall, the results from the crop simulation model show an overall increase of 33%

in the yield of rice in the time slice of 2020-2039 as compared to the baseline of 1990-2000. Similarly, in the time slice of 2040-2059, the average increase in yield of rice from baseline is 23.06%. Furthermore, in the time slice from 2060-2079, the increase in yield from baseline is 18.7% (Figure 23).

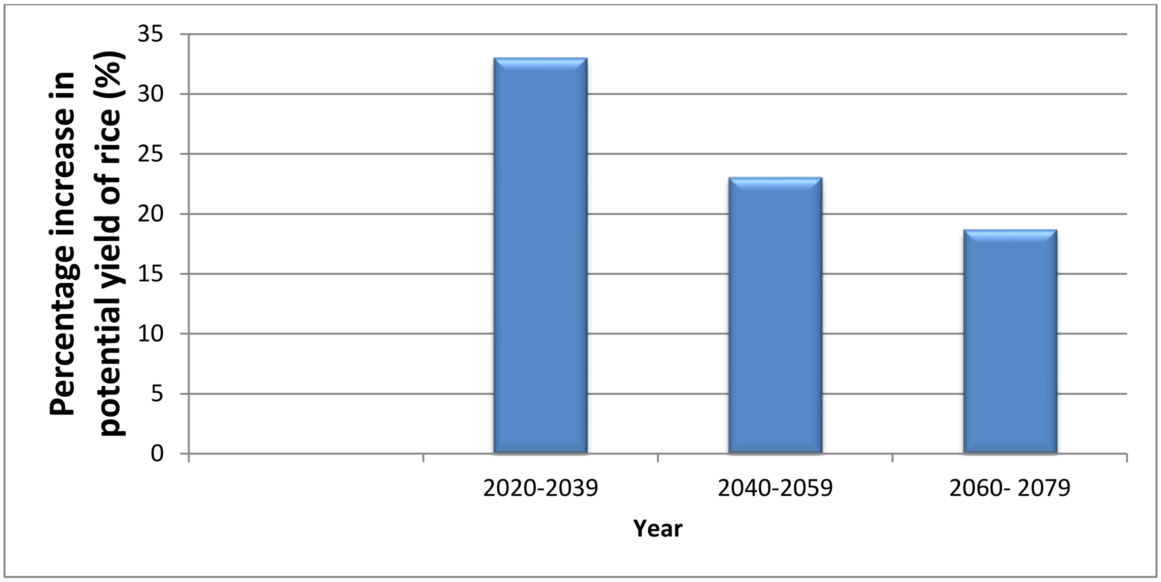


Figure 23: Future projections for potential yield of rice in Karjat

It is interesting to note that while the individually, all the three time slices show an increase in yield with respect to the baseline, on comparing amongst the three time slices, the average yield from 2041-2058 shows a 1.6% decrease in yield from the average yield in 2020-2038. Moreover, the average yield from 2061-2078 shows a 3.38% decrease from the average yield from 2041-2058. Therefore, despite an overall increase in yield as compared to the baseline, the yield of rice shows a decreasing trend from the 2020s to the 2070s.

Although most sensitivity analyses show a decrease in rice yields across various regions, there are several global as well as national studies that indicate an increasing in the yield of rainfed rice. For example, the assessment done for the coastal region (which includes the Konkan region), the INCCA report, 2010, projects upto a 35% increase in the yield of rainfed rice by 2030s as well. In addition to this, in another study doen by IFPRI, one of the models used in the ensemble, the CSIRO GCM, showed a 6.5-23.4% increase in rainfed rice. Studies done by the Economic Research service of the USDA conducted for rice import and export from Southeast Asian and South Asian countries also shows an overall increase in rice export to other countries through the years (Figure 24).

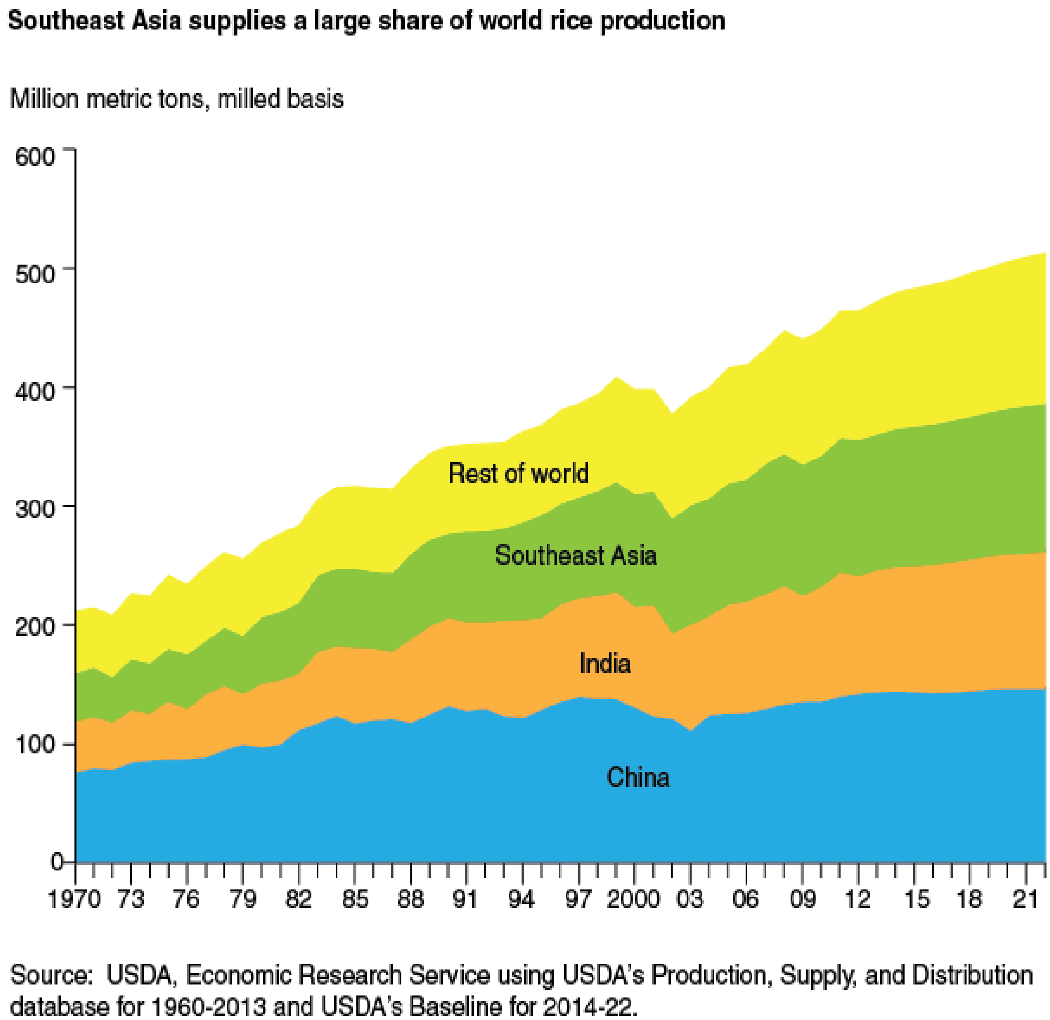


Figure 24: Projected supply of rice from countries in the future

10.3.2 Indicative results on productivity of selected crops in the future based on climate modeling results

Based on the literature review on the possible impacts of increase in temperature on crop productivities and the climate modeling outputs from the project, implications for select crops in Maharashtra, based on their distribution across the state, were arrived at. The crops that were selected were, cotton, rice, sorghum and soybean. The crop-wise findings are as follows.

Cotton

Findings from the literature review

1. Impact of rise in temperature: A temperature increase of 1.85°C in the A1B scenario will result in no significant change in yield in central India. However, a

3.2 rise in temperature would lead to a 268 Kg/ha decline in yield in Central India (Reference: Hebbar, K.; Venugopalan, M.; Prakash, A.; Aggarwal, P.Simulating the impacts of climate change on cotton production in India Climatic Change, Volume 118, Numbers 3-4, June 2013 , pp. 701-713(13)

2. Impact of Carbon dioxide concentration: Cotton under elevated carbon dioxide level of 650 ppm and temperature of 40 degree centigrade was found optimum, leading to improved productivity (Reference: Vision 2025, CICR Perspective Plan, Central Institute for Cotton Research, Nagpur, ICAR)[32]

Cotton growing regions in Maharashtra

Nagpur, Wardha, Chandrapur, Akola, Amravati, Yeotmal, Washim, Buldana, Aurangabad, Jalgaon, Dhule, Nandurbar, Nashik, Parbhani, Hingoli, Jalna, Nanded and Beed (Fig. 25)

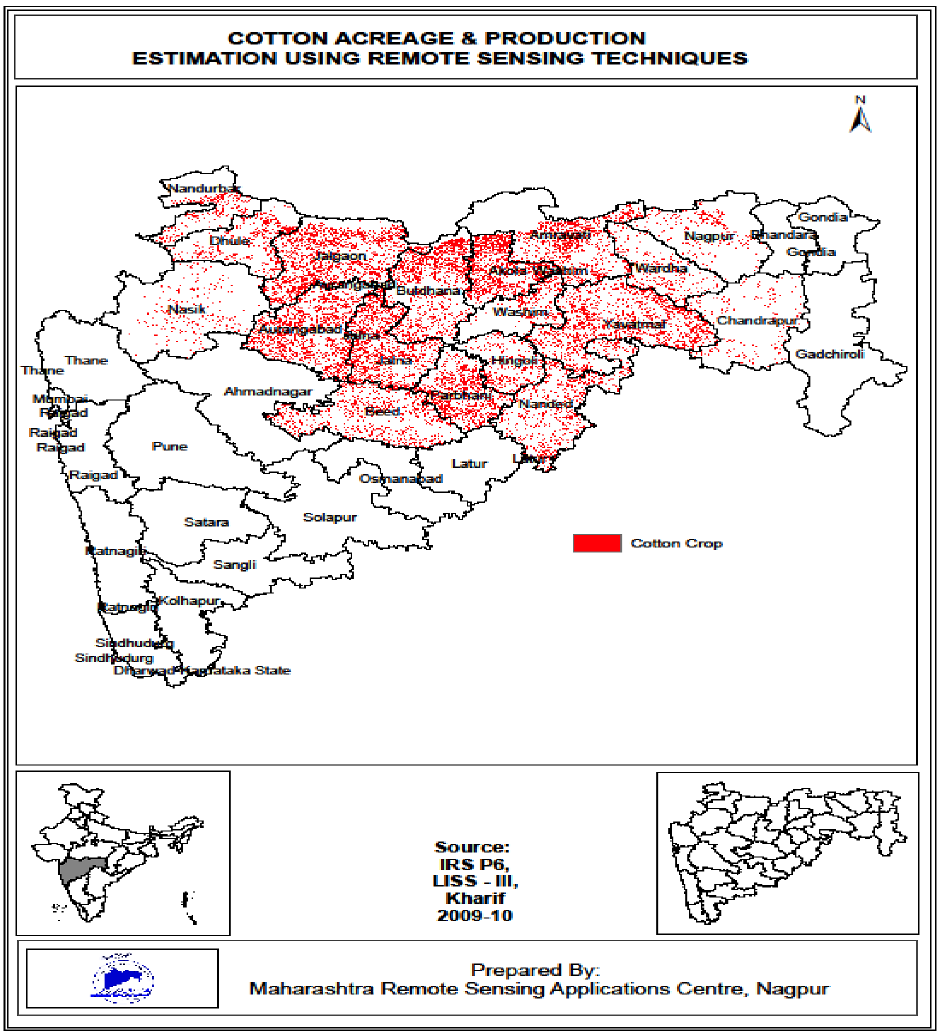


Figure 25 : Cotton growing areas in Maharashtra. (Source: MRSAC)

32 According to IPCC A1B scenario projections, CO_2 concentration will be 650 ppm by 2100

Figure 26. Climate projection outputs showing Difference in annual Mean temperature at 2m (2030s, 2050s & 2070s – Baseline), considered here are ensemble means for baseline and 2030s, 2050s & 2070s.

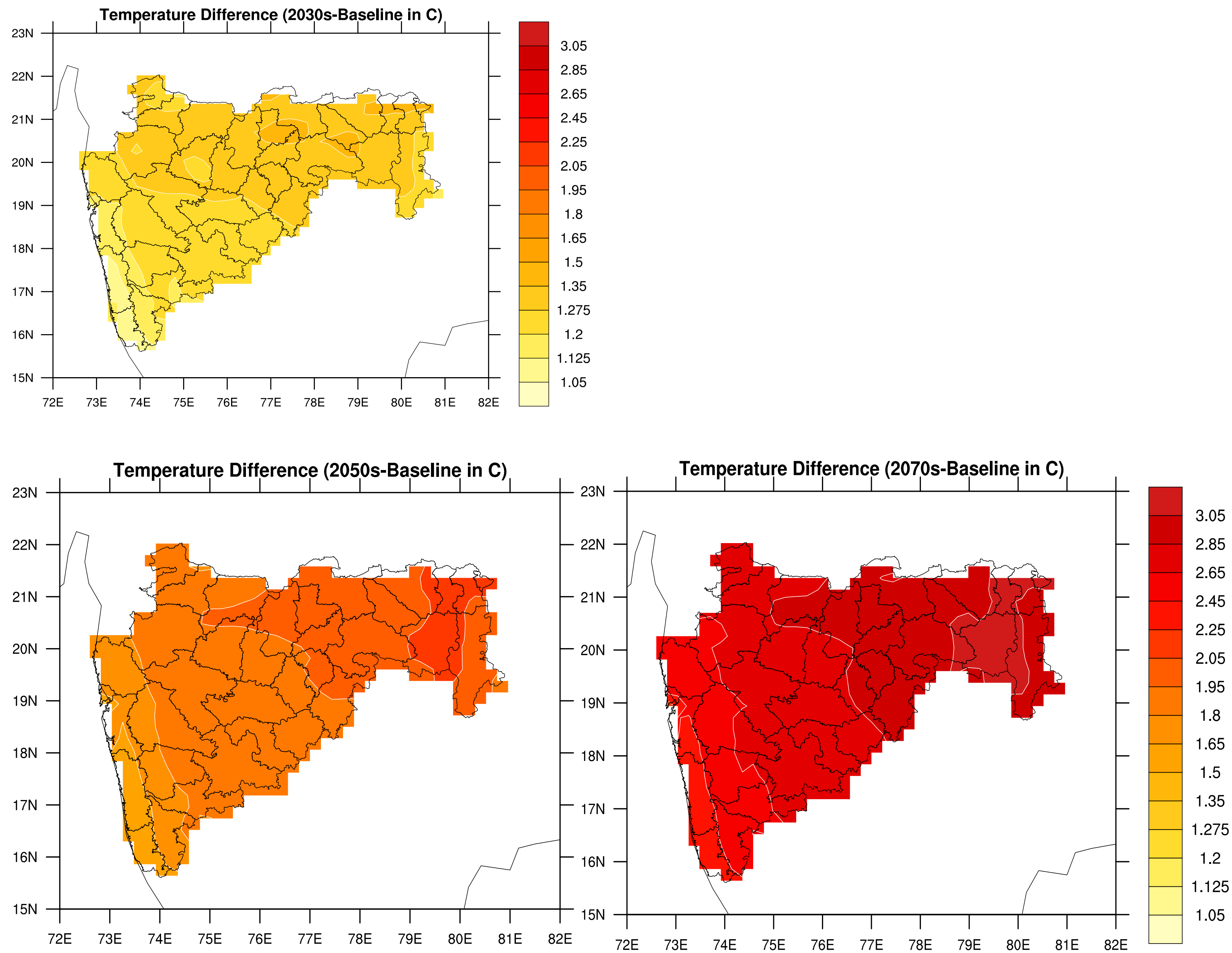


Table 22: Division wise climate projections

Administrative division	IMD climate normal: annual mean temperature (°C)	Projected increase in annual mean temperature (°C)		
		2030s	2050s	2070s
Amravati	27.21	1.44-1.64	2.2-2.35	3.06-3.46
Aurangabad	26.46	1.44-1.56	2.15-2.3	3.14-3.38
Nashik	26.79	1.4-1.68	2-2.4	2.82-3.3
Nagpur	27.19	1.18-1.4	1.95-2.2	2.88-3.16
Pune	25.22	1.15-1.28	1.65-1.95	2.46-2.74
Konkan	26.99	1.1-1.28	1.5-1.8	2.18-2.6

Conclusions

Based on Impact of rise in temperature: A temperature increase of 1.85°C in the A1B scenario will result in no significant change in yield in central India. However, a 3.2 rise in temperature would lead to a 268 Kg/ha decline in yield in Central India (Reference: Hebbar, K.; Venugopalan, M.; Prakash, A.; Aggarwal, P.Simulating the impacts of climate change on cotton production in India, Climatic Change, Volume 118, Numbers 3-4, June 2013, pp. 701-713(13)

- No negative impacts on cotton yield in the cotton-growing region in Maharashtra till the 2030s.
- There might be some negative impacts on cotton yields 2050s onwards but the degree of impact is not clear

Based on Impact of Carbon dioxide concentration: Cotton under elevated carbon dioxide level of 650 ppm and temperature of 40 degree centigrade was found optimum, leading to improved productivity (Reference: Vision 2025, CICR Perspective Plan, Central Institute for Cotton Research, Nagpur, ICAR)

Considering the temperature means in the baseline from IMD (Table 8) and that According to IPCC A1B scenario projections, CO_2 concentration will be 650 ppm by 2100 – the climate (only considering Temperature and CO_2 concentration) will be approaching an optimum for cotton productivity (650 ppm, 40 degree C).

Rice

Findings from the literature review

- Increase in temperature from 1 to 4 °C resulted in reduction in yield of Rice from 0 to 49% (S.D. Singh, Bidisha Chakrabarti and P.K. Aggarwal, Impact of elevated temperature on growth and yield of some field crops. Global Climate Change and Indian Agriculture, Case studies from the ICAR network, Edited by P.K. Aggarwal, 2009.)

- Increases in CO_2 concentration up to 700 ppm resulted in average yield increase of 30.73% by ORYZA1 model (P. Krishnan, D.K. Swain, B. Chandra Bhaskar, S.K. Nayak, R.N. Dash. Impact of elevated CO2 and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies. Agriculture, Ecosystems and Environment 122 (2007) 233–242)

Rice growing regions in Maharashtra
Rice is cultivated under assured rainfall condition. This region consists of 23 districts in the state as given below.

1) Konkan: Thane, Raigad, Ratnagiri & Sindhudurg
2) Vidarbha: Bhandara, Chandrapur, Gadchiroli, Gondia, Nagpur, Wardha, Washim Amravati and Yavatmal
3.) Western Maharashtra: Kolhapur, Satara, Pune, Ahmednagar, Nashik & Nandurbar. Dhule, Jalgaon, Solapur, Sangli

Conclusions
Based on the climate modeling outputs, the rice growing regions will face an increase in temperature beyond 1 degree centigrade from 2030s onwards and will upto 3.08 degree centigrade during the 2070s. This may lead to a decrease in rice productivity to less than 49% of the present yield, based on the literature review. However, on the other hand, the increase in carbon dioxide concentrations upto 700 ppm is said to result in an average increase of 30.73% from the present yield, which would cancel out the decrease in yield due to increasing temperature to a large extent. Thus, the net decrease in yield of rice due to increase in temperature will be less, if at all.

Sorghum

Findings from the literature review
- An increase in 50 ppm CO_2 increases yields by only 0.5%. The beneficial effect of 700 ppm CO_2 was nullified by an increase of only 0.9◦C in temperature (Chatterjee A (1998) Simulating the impact of increase in carbon dioxide and temperature on growth and yield of maize and sorghum. M.Sc. Thesis, Division of Environmental Sciences, IARI, New Delhi)
- A 1°C and 2.3°C rise in temperature resulted in 6.3% and 17.5% decline in sorghum yield in Bijapur (A2a scenario) (K Boomiraj, Suhas P Wani and PK Aggarwal, Impact of climate change in dryland sorghum in India,TNAU-ARS, ICRISAT, IARI, 2011.

Sorghum growing areas in Maharashtra
Wardha, Nagpur, Chandrapur, Buldhana, Akola, Washim, Amravati, Yavatmal, Latur, Osmanabad, Nanded, Hingoli, Parbhani, Aurangabad, Jalna, Beed, Satara, Sangli, Kolhapur, Nasik, Dhule, Nandurbar and Jalgaon.

Conclusions
On the basis of the climate modelling outputs for the sorghum growing region in Maharashtra, it can be concluded that sorghum yield is likely to decline more than 6.3% of the present yields from the 2030s to the 2050s and it may decline beyond 17.5% of present yields post in the 2070s.
Thus, an overall decline is the productivity of Jowar is likely as the beneficial impacts of increased carbon dioxide concentration are not substantial.

Soybean

Findings from the literature review

- Increase in temperature from 1 to 4 °C resulted in reduction in yield of 11% to 36% (S.D. Singh, Bidisha Chakrabarti and P.K. Aggarwal, Impact of elevated temperature on growth and yield of some field crops. Global Climate Change and Indian Agriculture, Case studies from the ICAR network, Edited by P.K. Aggarwal, 2009.)
- Free air CO2 enrichment (FACE) experiments on soybean show an almost 15% increase in yield due to elevation of carbon dioxide concentration to 550 ppm (S.D. Singh, Bidisha Chakrabarti and P.K. Aggarwal, S. Nagarajan and Madan Lal, Impact of elevated carbon dioxide on growth and yield of leguminous crops. Global Climate Change and Indian Agriculture, Case studies from the ICAR network, Edited by P.K. Aggarwal, 2009.)

Soybean growing regions in Maharashtra

Soybean is grown mainly in the Vidarbha (Amravati and Nagpur divisions) and Marathwada (Latur and Aurangabad divisions) regions of the state.

Conclusions
Based on the climate modelling outputs for temperature, the decline in soybean yields would be greater than 11% of the present yield in the 2030s and is likely to further decline in the 2050s and 2070s approaching a total decline of 36% of the present yield but not more. However, the decrease in yield might be limited to some extent by the increase in yield caused due to increased carbon dioxide concentration in the 2070s.

Limitations of approach
1. Crop projection information that is available in literature is not always for the A1B scenario – the scenario that has been used for our climate projections. Therefore there would be a mismatch in extrapolating information from a different scenario using climate information from the A1B scenario
2. We do not count in several important factors like rainfall, humidity etc.

3. Temperature increase projections are annual means (which includes summer and winter temperatures) whereas crops cycles do not extend for that long.

10.4 Climate change impacts on horticulture

Types of agricultural risks due to climate change have been identified as production risk, price or market risk, institutional risk, financial risk, and personal risk. Horticultural commodities are vulnerable to both quantitative and qualitative risks. Quantitative losses mainly occur in the form of decrease in yield whereas qualitative losses include loss in edibility, nutritional quality, calorific value, and consumer acceptability of fresh produce. The horticultural commodities are more vulnerable to both quantitative and qualitative changes as these are more perishable and since these are commercial crops, this results into financial losses across the chain. The losses in terms of value are huge as a lower quality produce does not get good price in the market. Moreover, due to change in weather conditions, the arrival patterns may vary causing glut in the market at one time and a shortage at other times. These demand-supply variations does not allow farmers to get the better prices of their produce as these being highly perishable commodities, these have to be sold immediately.

10.4.1 Impact on grapes

Grape is a very climate sensitive fruit crop. It is largely influenced by disease as an impact of climate change. More than 80 % of the grape cultivation in Maharashtra is confined to the agro-ecological zone hot semi-arid eco-region. Moisture stress and salinity are the key problems faced by the farming community for sustaining grape productivity. Seasonal changes in climatic conditions impact grape productivity through changes in terms of phonological events, such as budburst, flowering, harvest and finally yield.

Impacts on cultivation cycles are observed. Rainfall in November for the last three to four years has delayed pruning and thus harvesting, making it increasingly difficult to meet deadlines for supplies of grapes. Late onset of the monsoon and the unseasonal cyclone in 2009 reportedly damaged half the state's grape production in Nashik, Sangli, Solapur and Pune districts with severe impacts on wine production. Grape farming employs about three lakh people spread across these four districts.

Observations highlight huge damages to the crop due to erratic rainfall and extreme weather conditions. Hailstorm followed by cyclone in 2008-09 and 2009-10, untimely rains in 2011 has done immense damage to the grape crop. Unseasonal rains have been causing havoc in the grape growing regions of Nashik, Baramati and Sangli, destroying the crops and causing downey mildew affecting the quality resulting in lower prices of 30-40%. Unseasonal rains have damaged 800,000 tonnes of grape crop in Maharashtra resulting in an estimated loss of Rs 2,000 crore. Grapes grown for wineries on 10,000 acre have also been impacted. Crop loss has affected domestic sales as well as exports. Unusual cold waves hit grape production this year in the Nashik region of Maharashtra. The frost and the lowest temperature of 2.7 degree Celsius have damaged grape orchards in Nashik district.

Increasing temperature and changes in the rainfall is likely to affect the crop growth cycle. Because of rise in temperature, grapes will develop more rapidly and mature earlier. The faster maturity and higher temperature induced ripening will make lessen storage period in trees/ plants. They will overripe at an early date. Pollination will be affected adversely because of higher temperatures. Grape farms have been adversely affected in the state due to cold waves, damages including cracking of grape beads. The leaves of the plant are damaged so badly due to cold that the photosynthesis is hampered and productivity is greatly decreased. Based on climatic conditions, vine growing areas are classified into cold, cool, warm and hot regions. However, yearly climatic variation may shift the classifications of growing areas.

10.4.2 Impacts on oranges

An orange plant has about eight years of life and quality of the fruit goes down with the plant's age. Citrus content also lowers gradually in the fruit, affecting its prices in the market. Changing climate conditions have hit plant growth adversely, affecting the life span of plants. Plants now become old in a short duration than before due to increased temperatures and thus affect overall crop production.

Temperature has a profound effect on the quality of orange fruits. When temperature rises beyond 40-410C, the fruits are affected due to intense heat and bright sun rays. In Vidarbha, summer temperatures often go beyond 450C. This requires frequent irrigation of the crop at close intervals of 5 to 6 days to keep the atmosphere around the tree humid and cool. Mulching also helps to prevent evaporation from soil and keeps its temperature low. Extreme low temperature in winters is also detrimental for the growth of orange plants. Shortage of water also reduces the uptake of nutrients and limits the development of fruits in a normal manner. Shortage of water also reduces the size of fruits.

Dry spells have an impact on the production of the crop. 2008 reported huge losses with production in that season only about 3-5%. About 15 per cent of the fruit crop was damaged due to rising heat and untimely hailstorm in 2010. The hailstorm caused fruits, still in the nascent stage, to fall off and caused black patches on those left on the trees. Erratic rainfall in the region results in upsetting the process of sprouting of shoots into flowers and fruits.

One of the prominent effects on the crop is impact on flowering and fruiting. Delay in monsoon, dry spells of rains, and untimely rains during water stress period, supra-optimal temperatures during flowering and fruit growth, hailstorms are some of the reasons impacting crop growth.

10.4.3 Impact on mangoes

The Mango tree is well adapted to tropical and subtropical environmental conditions. It can be cultivated until up to 1300 m above mean sea level. However, commercial cultivations are limited to areas below 600 m above mean sea level. Optimum temperature for mango cultivation is 27-30 degree C. Mango is successfully cultivated in areas where annual rainfall range from 500-2500 mm. For a successful crop, most important thing is the distribution of rainfall rather than the amount. A dry period of 3-4 months is an essential prerequisite for successful flowering of mango. Rains at flowering may affect yield due to pollen wash off.

Specially in areas when prolonged dry periods exist, it is imperative to irrigate the plants in the first three years after planting. Frequency and amount of irrigation depend on rainfall and soil properties. For mango the most critical periods of moisture requirements from flowering to fruit maturity and leaf bud burst to leaf maturity. From leaf maturity up to flower bud burst irrigation must be withheld. Irrigation during this period adversely affect flowering.

Cold winter and unseasonable rains lead to a severe shortage in production of the Alphonso variety. Areas in Konkan region where Alphonso is grown was affected by harsh winter affecting the fertilisation process of the crop. Alphonso production in Maharashtra's Sindhudurg and Ratnagiri district has been dropping at a steady rate of 15% annually since 2008. Weather fluctuations, frequent weather changes like cyclones, hailstones, increasing pest attacks and shortage of pesticides have been some of the attributing reasons. Sudden increase in temperatures can lead to pre-mature fruit-drops damaging the crop. Even a minor deviation or fluctuation in the weather or temperature disturbs the production cycle of Alphonsos.

Low temperatures expose the fruit to pest infestation. For pollination and the mango fruit to mature, a temperature of 30-36ºC is ideal. High temperatures burn the flowers out resulting in a drop in yields.

The prolonged cold weather and moisture in the atmosphere could affect the crop and cause delay in fruit formation. If the fruits ripen during early monsoon, possibilities of worms affecting them are more. This would bring down the quality of the fruit and the yield. The yield will further decline if there are pre-monsoon showers. Fruit fall from rain would occur, causing loss to the growers. Thus fluctuating weather and sudden changes in temperature lead to large scale dropping of the fruit, burning of fruit apart from attacks from pests.

10.5 Climate change impacts on livestock

In India livestock is an integral part of agriculture systems. Often cropping pattern is interlinked to availability of fodder for the livestock, an important component of food security in India. Poultry, livestock and other farm animals will suffer due to climate changes because higher temperatures will increase the number of new diseases directly or indirectly affecting them. For instance exposure to drought and excessive humidity or heat renders cattle more vulnerable to infections. Also, alternating drought and heavy rainfall cycles provide a good environment for midge and mosquito vectors that are linked with outbreaks of vector-borne livestock diseases. Poultry is similarly affected by excessive heat or rainfall.

Increased temperatures and humidity levels causes the animals to have increased body temperatures, which results in declined feed intake, disturbed reproductive functions, and low milk yield. High temperature and increased thermal stress also negatively impact reproductive rates of cattle. Limited availability of water could further impact reproductive functions and also milk production. The major impacts of climate change on livestock have been on diseases that are vector-borne. Increasing temperatures have supported the expansion of vector populations. Changes in rainfall pattern can also influence an expansion of vectors during wetter years.

Direct impacts on livestock would be felt in the form of elevated body temperatures, increased respiration rates, decrease in feed intake and nutrient utilisation, all of which will invariably have an effect on milk production potential and reproductive performance of the animal. Indirect impacts are to be observed in the form of impacts on land and water availability, decline in feed quantity and availability and emergence of new diseases. Some of the causal factors include;

1/ Heat Stress in animals: The rise in ambient temperatures and increase in average Temperature Humidity Index (THI) creates heat stress conditions in dairy animals and significant changes in feed intake and other physiological changes. Experimental studies from India have shown that milk yield of crossbred cows is negatively correlated with THI. The influence of climatic conditions on milk production is also observed for local cows, though they are more adapted to the tropical climate. The productivity of Sahiwal cows also show a decline due to increase in temperature and relative humidity. In case of buffaloes, heat stress has detrimental effect on the reproduction of buffaloes.

Exposure of sheep to thermal stress affects voluntary feed intake and may affect maintenance requirement. A change in the climate parameters of the region is bound to threaten the habitat of these animals and the quality of the fibres.

2/ Milk production: There is normally a decrease in milk production for cows under heat stress. This decrease can be either transitory or longer term depending on the length and severity of heat stress. These decreases in milk production can range from 10 to >25%. High producing crossbred cows and buffaloes will be impacted more than indigenous cattle.

3/ Susceptibility to extreme events: Besides being susceptible to increased heat stress from climate change, the livestock are also exposed to the increased risk of extreme events. Every year thousands of cattle are lost due to heavy rains, floods and cyclones in various parts of the country. Severe droughts conditions affect the feed and fodder availability and cause serious water shortages.

10.6 Climate change impacts on marine fisheries

Changes in the climate can affect the fisheries sector through many pathways; both direct and indirect. The known direct effects of climate change include changes in the abundance and distribution of exploited species and assemblages and increases in the frequency and severity of extreme events, such as floods and storms, which affect fishing operations and infrastructure. The indirect effects include: changes in aquatic habitat (quantity and quality), ecosystem productivity and the distribution and abundance of aquatic competitors and predators/diseases; impacts on food production affecting livelihoods and food security and cultural impacts on fishing communities related to livelihood loss, migration etc .

Climatic changes are likely to impact the geographic distribution and mortality of marine organisms. Depending on the mobility of the species, the area they occupy might expand or shrink. Any distributional changes will directly affect the nature and abundance of fishes.

Fish spawning is especially sensitive to temperature, and several species of marine fish are known to spawn only at a particular water temperature. Climatic changes are already affecting the availability, behaviour and distribution of some commercial fish.

Increase in sea/ river water temperatures has an impact on fish breeding, migration and harvests. Increase in temperatures may affect fish spawning activity and result in shifts to a season when the temperature is around the preferred optima. Shift in breeding season has an impact on the reproductive competence of fishes. Changes in behaviour directly linked with climatic changes are also visible in oil sardines, a coastal, schooling fish with a high reproductive rate. Distribution effects have been observed in case of oil sardines. Its distribution is restricted to the Malabar region along the southwest coast. Due to the current warming of the Indian Ocean, the oil sardine has already spread to the northern and eastern boundaries of its original distribution in the Indian ocean. While the oil sardine is an example changes in the temperature of the seas will have an overall impact on many of the types of fish available, affecting not only the value of Indian commercial fishing but the food and livelihood security of many coastal communities.

The potential impacts of climate change on fish harvests can be summed up as below;

1) Climate change may cause a decrease in the abundance of certain species while promoting the abundance of others.
2) Changes in abundance of species will result in fishermen catching greater or less fish, and the changes in harvests will affect livelihood opportunities in fish harvesting and processing
3) Changes in harvests will cause a change in prices. If supplies decrease then prices will increase and vice versa.
4) Changes in harvest volumes, prices and input costs together affect incomes and profits in harvesting and processing of fish
5) Reductions in income and employment as an outcome of resource changes are likely to result in stresses at both the family and community level.

Negative effects of climate change on fishery production include;

a) Temperature: Organisms at the extremes of their tolerance limits may face stress due to increased temperature and oxygen demands. Also, local conditions may become unsuitable for a number of established species that may then move polewards or to cooler offshore water, or replaced with other species. The changes may also result in productivity changes and shifts in the relative abundance of species. Increased temperatures are also likely to affect the physiological processes of fish and thereby affect their ability to survive and reproduce.

b) Sea level rise, extreme weather events/Precipitation Flash floods may displace eggs from their natural habitats and increase the chances of mortality due to starvation or predation. Other parameters include altered time of spawning, altered time of migrations, altered time of peak abundance and coastal profile changes.

c) Salinity: Species may not tolerate changes in salinity and there might be a general growth reduction in organisms. Salinity and temperature together influence important physiological responses such as growth, metabolic rates and blood iron.

d) Acidification: The increase in ocean acidity is likely to decrease the calcification rates of organisms like shrimps, oysters and mussels.
e) Additional problems are likely to arise with non-native species invasions, declining oxygen concentrations and possibly increased blooms of harmful algae

Table 23 below summarizes the effects of climate change on fishery resources.

Table 23: Effect of climate change on fishery resources

Indicator	Measuring/ Causing
SST, Temperature, tides	Upwelling, temperature stress on habitats Movement of fish towards the poles/ vertical migration Change in growth, spawning and dispersal, catch reduction
Rise in acidity	Damage to calcareous exoskeleton
Sea Level Rise	• Loss of coastal fish breeding and nursery habitats (e.g. mangroves and corals) • Changes in sex ratio • Altered time of spawning • Altered time of migrations • Altered time of peak abundance • Coastal Profile changes • Increased exposure of coastal areas to storm damage • Inundation, damage to properties and livelihood
Ocean Currents	Changes in fish recruitment success, changes in species dispersal, ecosystem changes and catch reduction
Salinity	Changes in species composition in coastal/ estuarine regions
Storm surges	Damages to properties and life
Floods	Salinity reduction in coastal waters; species dispersal
Turbidity	Productivity

Source: FAO, 2007

10.7 Implications for food security

Food security is the outcome of food production system processes all along the food chain. Climate change will affect food security through its impacts on all components of global, national and local food production systems, which is projected to affect all four dimensions of food security, namely food availability; stability of food supplies; access to food and; food utilization. Impact on the agriculture and allied sectors thus have large detrimental effects on availability of food, livelihoods dependent on it and the overall economy of the country. Any change in climatic determinants can not only lead to adverse impacts on food security and nutrition but also essentially affect well being of millions deriving livelihood and income from these activities. Agriculture and allied sectors therefore exhibit high sensitivity to climate stresses.

Food security may be at risk in the future due to the threat of climate change leading to an increase in the frequency and intensity of droughts and floods, thereby affecting production of small and marginal farms. Droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, and heat waves are known to negatively impact agricultural production, and farmers' livelihood. The projected increase in these events will result in greater instability in food production and threaten livelihood security of farmers. Increased production variability could be perhaps the most significant impact. All agricultural commodities even today are sensitive to such variability. Producing enough food for meeting the increasing demand against the background of reducing resources in a changing climate scenario, while also minimizing further environmental degradation, is a challenging task.

Any change in rainfall patterns poses a serious threat to agriculture, and therefore to the country's economy and food security. It is predicted that because of global warming, this already fickle weather system could become even more undependable. Agriculture will be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shifts in the timing of the rainfall.

The uncertainties associated with climate change do not permit a precise estimation of its impact on agriculture and food production. However, what is happening already in terms of changing seasonal patterns and respective increases in temperature, moisture concentrations and CO2 levels is likely to have diverse impacts on ecosystems--and therefore on crops, livestock, pests and pathogens. The physiological response of crops to changing climate is expected to be varied. Although some positive outcomes are expected, the new climatic conditions are more likely to have negative impacts such as a rise in the spread of diseases and pests, which will reduce yields.

Most studies on the impact of climate change on agriculture come to the same conclusion that climate change will reduce crop yield in the tropical area. The regional inequality in food production resulting from climate change will have a very great implication for global food politics. Even without the challenge of climate, food security is an issue in the tropical areas considering that almost 800 million people in the developing world are already suffering from hunger.

It is known that many agricultural systems are seasonally dependent and thus sensitive to climate change. Crop and livestock production need a specific range of weather conditions at particular times, for optimal growth. Changes in the climate can shift these optimal windows. The most vulnerable agricultural systems are the arid, semi-arid, and dry sub-humid regions of the developing world. In these regions high rainfall variability and recurrent drought/flood cycles disrupt crop development, particularly where crops are grown in marginal lands with low inputs.

Extreme high and low temperatures cause physical injuries to crop plants and damage the grain. Injuries are inflicted by high temperatures on the exposed area of plants, scorching leaves and dehydrating the plant. Young seedlings also dehydrate quickly when soil temperature rises. Temperature rise in lower latitude regions accelerates the rate of respiration, excessively leading to sub optimal growth. For example, rice productivity is estimated to decrease under climate change due to its sensitivity to temperatures that cause damage to the plant, thus affecting yield.

Increased temperatures have multiple impacts on crop productivity depending on the biological characteristics of the specific crop and the time of the heat stress in relation to its development. Higher daytime temperature accelerates plant maturity and results in reduced grain filling, while higher night temperatures increase yield losses due to higher rate of respiration. Episodic heat waves can reduce yields, particularly when they occur during sensitive developing stages, such as the reproductive phase which increases sterility. Higher level of ozone in the lower atmosphere (troposphere) also limits growth of crops. The severity of diseases caused by fungi, bacteria, viruses, and insects are anticipated to increase with global warming. The spur in the population of pests and other vectors is related to the interplay of different factors such as increases in temperature, changes in moisture concentration, and a rise in atmospheric CO_2. Changes in environmental conditions are likely to result in the northward extension of certain diseases and pests, more generations of pathogens per season, and a better capacity to survive the winter, thus increasing their prevalence and range. Further compounding the problem is that as farmers change crops and cropping patterns to adapt to the changing climate, their crops will be exposed to new kinds of diseases and pests.

The above trends have considerable implications for food and livelihood security, including the possibility of creating conflicts at the local and regional level over scarce natural resources. Water security issues in the context of changing demographics and the growing competition for various is likely to further aggravate the risks in the agriculture sector.

Climate change may threaten livelihood opportunities within the food production sectors in two main ways: Firstly, increases in the frequency and the intensity of extreme weather events may expose the agricultural sector to greater productivity risks and possible revenue losses that could lead to abrupt layoffs; and secondly, changing weather and precipitation patterns could require expensive adaptation measures such as relocating crop cultivation, changing the composition or type of crops and increasing inputs such as feed, fertilizers and pesticides which may lead to economic denigration and job loss. IPCC projects with high confidence that "smallholder and subsistence farmers, pastoralists and artisanal fisher folk will suffer complex, localized impacts of climate change".

While the lack of sufficient income to purchase food is a major factor causing households to face food insecurity, hunger itself contributes to poverty by lowering labor productivity, reducing resistance to disease and depressing educational achievements. This vicious cycle initiated between "food insecurity-malnutrition" and "livelihood loss-poverty" may impede economic progress of our country. In some areas where livelihood choices are limited, decreasing crop yields may threaten famines, or where loss of landmass in coastal areas is anticipated, migration might be the only solution. Another noteworthy dimension of the problem is the likely implications for global and domestic trading regimes and market prices of farm inputs and outputs under the changing climate scenarios. When agricultural production is impacted, current balances of trade may get altered and most likely to be negative. Increase in food prices can increase the risk of hunger and malnutrition.

Existing projections indicate that future population and economic growth will require a doubling of current food production, including an increase from 2 billion to 4 billion tonnes of grains annually. However agricultural production in many countries including India would be severely compromised by climatic variability and climate change. Increase in frequency and patterns of extreme weather events will affect the stability of, as well as access to food supplies. The impact of climate change on behaviour of pests and diseases still remains largely unclear, while their economic implications are being increasingly felt. Further ahead, the impacts of climate change also pose a serious threat to food security and need to be much better understood. Therefore, developing models that will be able to produce crop forecasts a season ahead is crucial for future food security, especially in very vulnerable regions.

10.8 Adaptation strategies for Maharashtra's agriculture sector

The biggest challenges for agriculture in Maharashtra are to increase productivity and protect farmer livelihoods in a scenario of climate change, over-extraction of groundwater, and soil degradation. This calls for a combination of scientific knowledge and economic incentives to encourage the sustainable intensification of agriculture, diversification to less water-intensive crops, value addition through agro processing, and provision of marketing and infrastructure to farmers.

10.8.1 Key recommendations

- Farmer advisories by agricultural extension agencies on appropriate crops as temperature and rainfall patterns change and the suitability of climate for crops is altered.

- Research on high yielding varieties of hardy traditional crops (including summer crops, traditional early sowing rice variety like bhadas in Konkan) and promotion of heat-tolerant and early maturing varieties.

- Provision of frequent and localized weather forecasts and crop-specific agricultural advisories to encourage farmers to change cropping practices (e.g. delay sowing dates, protective irrigation). Denser networks of monitoring stations for better pest and disease surveillance and climate services.

- Measures to conserve soil moisture for winter and summer crops, and improved planning and construction of watershed management structures like percolation tanks and check dams.

- Improvement in post-harvest management and improved access to cold storage and warehousing with credit, subsidies, and training of farmers on good practices.

- Preservation of good agricultural land in peri-urban areas through designation of urban food zones around major cities to source the city's food (e.g. vegetables, milk, eggs), reduce its carbon footprint, and secure its food supply chain against climate risks.

10.9 Adaptation action plan

10.9.1 Adaptation action: Safeguard farmers against climate risks through improved access to climate services and risk management strategies

Present status and rationale:

Installation of automated weather stations and mobile based weather and crop advisories are being provided by agriculture universities, KVKs, and IMD. Strategic research on resistant cultivars and technology demonstration is being carried out by agriculture universities, research stations, KVKs, and under the National Initiative on Climate Resilient Agriculture, launched by the Indian Council of Agricultural Research (ICAR) in February 2011. However, agriculture R&D in India remains very low as a percentage of agriculture GDP. For instance, this figure (in 2009) was 0.4 for India, 0.37 for South Asia, 0.61 for Sub-Saharan Africa, and 1.14 for the Caribbean.

Some Krishi Vikas Kendras in the state are using community radio and mobile sms for disease advisories, but this needs to be made more interactive, timely, and customized to individual farmers' crops and lands. In a pilot project, Tata Consultancy Services has developed a mobile-based platform for disease forecasting and advisory services. It connects farmers with agricultural experts who can study photos of crop diseases and recommend suitable measures. This pilot project demonstrates the potential scope for private enterprise. The National Initiative on Climate Resilient Agriculture aims to study the impact of climate change on pest and disease dynamics, changes in crop-pest/pathogen relationships, changed profile of insect pests and emergence of new biotypes due to climate change, and development of forewarning system. Under the aegis of this Initiative, the National Centre for Integrated Pest Management works to

- assess changes in crop-insect pests/pathogen relationships under changing climate and emergence of new biotypes
- model pest and disease impact on rice, pigeonpea, groundnut, tomato and mango
- develop database on pest-weather interactions; generate pest distribution maps; and document emerging pests
- conduct controlled experiments to assess direct and host mediated impacts of climatic variables among trophic levels
- development e-pest surveillance through networking of research centres
- model the frequency and intensity of pest outbreaks
- develop adaptation strategies for pest management under climate change scenarios

Key components of action:

- Expand the network of farmers with access to climate services and weather advisories, particularly small farmers. Disseminate information through Gram Panchayat-level knowledge hubs.
- Institute knowledge network of research institutions (IITM, IMD, Agriculture universities and Colleges and Research Stations) to develop integrate seasonal climate

forecasts into decision support systems/ applications and provide localized and crop-specific agricultural advisories.

- Develop database of cultivars of important crops with features such as drought resistance, salinity tolerance, and pest resistance.
- Provide seeds for short duration and improved varieties of minor millets (e.g. ICRISAT varieties), intercropping with short duration red gram and soyabean, drought tolerant variety of Bengal gram (e.g. drought tolerant Digvijay variety of Bengal gram developed by the Mahatma Phule Krishi Vidyapeeth Rahuri).
- Increase allocation of funds to State Agricultural Universities for priority research on high yielding varieties of heat-tolerant and drought-resistant crops.
- Develop a network of gene banks to exchange germplasm and establish good practices for maintaining gene bank base collection and seed vault (community level and at state level) and use for isolating resistant traits.
- Scale up mobile-based disease surveillance and institute forewarning system for emerging pests and pathogens in different agro-climatic zones, and provide customized advisories in partnership with agriculture universities, research stations, and private companies.
- Educate farmers through KVKs on likely changes in pests and pathogens under climate change scenarios and their prevention/treatment.
- Simplify and explain crop insurance to farmers and encourage the participation of non-loanee farmers. Increase access to livestock insurance. Extend the Modified National Agriculture Insurance Scheme to more villages and the Farmers Personal Accident Insurance Scheme to include more weather perils. Scale up pilot weather-based crop insurance schemes and expand the automated weather station network to provide accurate site-specific weather data. (This adaptation action is elaborated in the Livelihoods chapter)

10.9.2 Adaptation Action: Enhance resilience of farming systems through diversified cropping patterns and farming systems and soil conservation

Present status and rationale:

Sorghum (jwari/ jowar), Pearl millet (bajri / bajra), and finger millet (nachni / ragi) have always been part of Maharashtra's traditional diet. Millet crops are very important for adaptation too climate change as they need less water and have carbon-fixing properties. But their economic value currently does not provide incentives to farmers to grow these crops. So a market needs to be created and appropriate incentives and institutional support need to be provided. Heat tolerant varieties of millets are being developed under NICRA and at ICRISAT but farmers need high yielding varieties of these crops.

Pulses like tur dal are not only part of Maharashtra's traditional staple diet, but are also hardy crops that require low soil moisture. They are well suited to enhance the adaptive capacity of farmers in Marathwada, Western Maharashtra, and Vidarbha regions of Maharashtra. 33 districts of Maharashtra are covered under the National Food Security Mission for pulses. In 2010-11, Maharashtra won 'Krishi Karman' award for the best performance in pulses production, accounting for 18% of the country's pulses production. Some of the good practices adopted in the State include the following.

- In situ soil moisture conservation through construction of tanks
- Adoption of Crop e-Pest Surveillance Project under the Rashtriya Krishi Vikas Yojana
- Extension activities through Krishi Mahotsav and Dhanya Bazaars
- Focus on project based agriculture extension for 100-500 hectare group farming, in which end to end services from seeds, nutrients, plant protection, training to farmers and market facilities are provided
- Agricultural advisory through SMS service

Research and demonstration activities are being conducted at agriculture universities, under NICRA and the All India Coordinated Research Programmes of the ICAR, but farmers need access to high yielding varieties of short duration heat tolerant cultivars.

Improving farmers' access to soil testing facilities can induce more rational application of nutrients and reduce the requirement of irrigation water. This, however, requires regular soil testing so that farmers can adopt the optimum nutrient mix suited to their soils and crops. Even if soil testing is free of cost – or farmers are willing to pay a small fee – the opportunity cost of time spent on getting a single soil sample tested is estimated to add up to more than Rs 300 (Mukherjee 2010).

Precision farming uses scientific knowledge about field-level variability in farming conditions and crop needs to recommend just the right amount of nutrients and other inputs. It takes advantage of geospatial tools and information technology. The Horticulture Training Centre of the Maharashtra State Agriculture Marketing Board has planned a course on prevision farming, but it needs to be promoted through all agricultural universities and extension offices. In addition, outreach to farmers can be conducted through ATMA (Agricultural Technology Management Agency) on reduced on-field evaporation losses through mulching and reduced tillage (or zero tillage).

The draft State Organic Farming Policy recommends setting up organic farming sections in all four agriculture universities in Maharashtra. Direct market access to organic farmers can be provided by inviting buyers to marketing mandis and by facilitating contract farming. Along with this, certification of organic farms and produce would need to be facilitated. While the organic farming model promotes on-farm production of biofertilizer and biopesticides, small and marginal farmers may be unable to spare the land or have adequate livestock for this purpose. For this purpose, village-level sale points for biofertilizers and biopesticides can be set up.

Key components of action:

- Promote diversification of cropping pattern to include hardy crops and adoption of integrated farming system approach. Advise farmers on sustainable and profitable farming systems (e.g. rice-fenugreek-okra and rice-onion-cowpea in heavy block soils) and sensitize them about the advantages of intercropping and crop diversification for climate change adaptation.

- Develop, demonstrate, and disseminate heat tolerant and short-duration varieties of pulses (esp. chickpea and pigeon pea) and high yielding varieties of millets. Similarly, promote heat-tolerant indigenous cattle breeds.
- Provide start-up funds for community-managed grain banks to supply good drought-resistant seeds and to maintain stocks for food and fodder security.
- Promote summer crops such as summer maize to address security of food and especially fodder in drought prone areas of Marathwada region as well as districts like Solapur, Usmanabad, Amravati and Gadchiroli. This would enable development of dairy sector in areas like Dhule and Hingoli where livelihood diversification is needed.
- Promote soil conservation by adopting international best practices of maintaining records of soil quality. Train farmers on precision farming techniques (e.g. fertilizer microdosing) to conserve water, soil, and nutrients.
- Extend the ongoing initiative to develop village-wise soil fertility index for major and micronutrients under the Rashtriya Krishi Vikas Yojana to develop village-level drought risk maps showing soil quality, irrigation availability, and zones where drought has greater impact on crops. Such maps can be developed for every village in a participatory manner and digitized in a GIS platform.
- Adopt a State Organic Farming Policy that promotes nutrient recycling on integrated livestock and cereal production farms and supports village-level production of organic manure for small farmers.
- Establish market linkages and branding for farmers cooperatives, e.g. with urban or export markets for organic produce, or with the poultry feed industry or health food manufacturers for millets.

10.9.3 Adaptation Action: Enhance resilience of agricultural livelihoods through value addition and market access

Present status and rationale:

Horticulture production is of immense importance to Maharashtra, but it faces the dual challenges of climate change and economic globalization. Horticulture farmers remain price takers and lack direct access to markets. Moreover, climate change will change the timing of maturation of fruits, increase disease occurrence, increase the need for irrigation, and could negatively impact quality. Maharashtra agro-industrial policy (2010) recognises the tremendous potential for higher value addition through processing. It identifies potential clusters of districts for fruits, vegetables, and dairy processing based on production strengths of different areas in Maharashtra. However there is need for end-to-end integrated value chains so as to make them domestically and globally competitive.

The UNO-IFAD assisted Convergence of Agricultural Interventions in Maharashtra (CAIM) project aims to reform wholesale markets and provide alternate market opportunities to farmers in six distressed districts of Vidarbha, viz. Akola, Amravati, Buldhana, Wardha, Washim and Yavatmal. In addition, the State Government set aside Rs 65.56 crore in the 2012-13 budget for the World Bank-assisted Maharashtra Agricultural Competitiveness Project in 33 districts. This is implemented by the Maharashtra State Agriculture Marketing

Board (MASMB) and also aims at improving farmer access to markets. Two of the measures under these projects which will improve farmer access to markets are:
1. Disseminate price information, weather forecast, market news and technical guidance through local language SMS to farmers – either directly or through field functionaries. This information will enable farmers determine the best timing and price of sale.
2. Eliminate cess on produce brought by local farmers to Shetkari Bazars organized by APMCs for direct marketing. Increase the number of Shetkari Bazars to every district and then every taluk.

Key components of action:

- Train self help group networks on climate resilient livelihood options and market linkages. For example, goat-rearing and poultry-farming are more resilient to rainfall variability than buffalo rearing as they require less green fodder and water.
- Increase value addition through agri-processing by establishing agri-processing clusters in vulnerable districts, training local entrepreneurs and self-help groups on agri-processing techniques and proposal development under the National Horticulture Mission, creating growers' associations and tribal cooperatives for marketing, setting up grading and packing centers for fruits and processed products, and sensitizing agricultural cooperatives network on climate proofing production and marketing.
- Incentivize field and post-harvest technologies and develop a network of decentralized food processing zones especially in Vidarbha. Promote cultivation and proccessing of durum wheat variety in districts like Nanded and Latur. Similarly exotic vegetable clusters can be developed at Buldhana, Thane and Satara districts to augment income generation of the farmers.
- Capacity building and training of the local communities across the state especially youth regarding urban agriculture as an alternative source of livelihood. Training centers to be especially developed at Gondia, Gadchiroli, Usmanabad, Nanded, Latur, Nandurbar and Kolhapur.

10.9.4 Adaptation Action: Secure food supply chains through enhanced access to cold storage infrastructure, warehousing facilities, and urban food zones

Present status and rationale

An estimated 30 -35 % of fruit and vegetable production is lost due to inadequate post harvest infrastructure in India. Fruit & vegetable crops extremely sensitive to heat and extreme events. Farmers become price takers due to inadequate storage, and also lose out due to inadequate grading and packaging. Around 460 cold storages have been set up in Maharashtra in the public, private and co-operative sectors with a capacity of 5.64 lakh MT, but these are mostly around Thane, Nashik and Mumbai. The Cold Storage Subsidy Scheme was initiated by the Maharashtra State Agricultural Marketing Board. In addition to capital cost subsidy provided by the National Horticulture Mission, the state government now subsidises the cost of multi-chambered cold storage (for multiple products). Warehousing facilities not only provide storage so that farmers need not be price takers, but in fact also provide an instrument of credit to farmers. The State Agro Industrial Policy 2010 aims to set up post-harvest infrastructure for cold storage, grading, and warehousing

Key components of action

- Expand the cold storage infrastructure to reach other districts, especially the horticulture growing districts of the Konkan region
- Revive defunct cold storages and establish new government owned cold storage facilities (especially for perishables and fruit crops) at the block level
- In 2 years: Pilot cold storage facilities in 2 blocks of 3 case study districts
- In 5 years: Establish cold storage units at block level in all districts
- Set up block level or village level operation and maintenance committees for the cold storage facilities
- Continue to encourage farmers to use accredited warehouses by offering credit-linked interest subsidy on pledge loans taken by farmers on stored produce
- Demarcate good agricultural land around large urban areas for development as food/ vegetable/ poultry zones in the city development plans, particularly in Mumbai, Pune, Nagpur, Nashik Aurangabad, etc. This will help reduce the growing city’s carbon footprint and secure its food supply chain against climate risks.

10.9.5 Adaptation Action: Block level setting up of cold storage facilities to increase the shelf life of key fruit crops or perishables in the State

Action category: In the purview of the post-harvest losses caused by the uncertainty in the climatic conditions, there is an observed need to establish government owned and managed cold storage facilities for the key income generating crops .In districts like Solapur, Gondia there is a need to enhance resilience of the farmers against the increasing crop failures by providing sufficient storage facilities. Further, there is a need to also establish local/block level operation and maintenance stations for these systems.

Rationale: In the state of Maharashtra, India, agriculture is a major source of income for majority of the population (60-70%) but still it has set backs in terms of post-harvest losses (25-30% of total agro-produce). Further, there are 9 agro-climatic zones in Maharashtra with diverse agricultural patterns and produce. Given this, the variety of agricultural produce needs to be transported to various locations. Hence, supply of commodities to remote locations becomes challenging due lack of infrastructure, higher costs of transportation, shorter shelf life of perishable fruits and vegetables. Similarly for small scale farmers in the remote areas, it is difficult to transport their produce on daily basis to larger markets due to unviable scale of economy.

Apart from the rate of penetration of mechanisation in the agriculture sector, factors like shifts in the growing seasons owing to the delay in the monsoon, irregular distribution of rainfall, extreme events like floods, drought or even cyclones may affect the overall production of the crops. As an example, in terms of the agricultural land under grape cultivation and grapes production, Nasik and Sangli districts are at forefront in the State of Maharashtra. In 2009-10, cyclone *Phyan* which hit the western coast of Maharashtra, destroyed the crop affecting the total crop production due to the extended rains, 60% reduction in the annual crop production was recorded[33].

These noteworthy damages clearly indicate the embodied sensitivities and poor adaptive capacities of these crops to withstand the climatic fluctuations. It is estimated that as much as 30 - 35 % of fruit and vegetable production is lost on account of lack of adequate post harvest infrastructure. Agricultural produce of the farmers do not get remunerative prices due to lack of grading, proper packaging and in turn there is huge post harvest losses. Hence solutions like storage facilities, as a crop conservation measure demand urgent attention to prevent losses.

Key components of the action:

1. Detailed assessment of the present cold storages with respect to their capacities and conditions in the state.
2. Reviving the existing defunct cold storages and establishing new Government owned cold storage facilities (especially for the perishables and fruit crops) at the block level and Village level in the various districts as per the requirement.
3. Setting up of block level or village level operation and maintenance committees for the cold storage facilities.

Expected outcomes:

1. Substantial reduction in the crop damages in the time of uncertain monsoon seasons.
2. Increased economic stability owing to reduced losses. With the availability of the storage facilities, the communities would be able to undertake cultivation of perishable vegetables on a larger scale adding to innumerable economic benefits.
3. Export fruits like Pomegranate especially districts like Solapur could be enhanced with the available storage facilities.
4. Increased shelf life of the crops.

Implementation:

Timeframe	**Short term:** Undertaking assessment of the Government as well as private owned cold storages in the state within one year of the project initiation. Establishing cold storage in at least 2 blocks in 3 case study districts out of 6 districts as pilot level project with the help of Agricultural Produce Market Committees (APMCs) and Co-operative societies functioning in the various regions of the State. Establishing block level Operation and Maintenance Committees (OMCs) for the cold storages established.

[33] http://business-standard.com/india/storypage.php?autono=418422, last viewed in October 2012

	Establishing the cold storage units and the OMCs could be undertaken in the year following the assessments of the existing cold storages. Undertaking the success rate assessment and the perception of the local users towards the advantages of the cold storage facilities.
	Long term: Establishing Government owned cold storage units at block level in all the districts of Maharashtra in next 3 years.
Links with the ongoing activities	**The State Agro Industrial Policy 2010:** the policy aims at development of agri clusters and end to end integrated value chains so as to make the sector more globally competitive. Under the policy the government also aims at setting up of post-harvest infrastructure for cold storage, grading, warehousing and market linkages. Our proposed concept fits perfectly in this framework and we expect substantial support both in terms of promotion through policies and financial support for implementation. **Cold Storage Subsidy Scheme:** Initiated by the Maharashtra State Agricultural Marketing Board (MSAMB), which provides financial assistance to the producer with subsidy @ 25 % of the total project cost with maximum limit of Rs 2.5 lakhs per project. Moreover, the beneficiary may get subsidy for more than one cold storage also, encouraging more of such units considering their need.
Nodal Government Department	For setting up of the cold storage units: **MSAMB** Local co-ordination and implementation support **: Agricultural Produce Market Committees (APMCs) and Co-operative societies** Overlooking department: **Agriculture Department.** **The Ministry of Food Processing in India.**

11. Forests and biodiversity of Maharashtra: climate change impacts and adaptation

11.1 Approach to assessing impacts of climate change on forests and biodiversity of Maharashtra

Climate change will pose additional stresses along with the existing pressures on forests and biodiversity of Maharashtra State. Various approaches have been developed to understand the possible impacts on the forests and biodiversity such as climate modelling, correlating the observation / long term monitoring with the climate variability, periodic monitoring the flowering and fruiting behaviour of plants, identifying monitoring the indicator species etc.

The species composition of habitats has a close relationship with the micro-habitat temperature and the precipitation along with other physical parameters. The forest canopy gap studies in the Western Ghats have shown that the multi-story evergreen forests have sun loving pioneer species followed by the shade loving secondary species in the subsequent canopy levels. The precipitation levels especially the spread over the year has immense importance to the regeneration of evergreen species in the Western Ghats and other riparian species in other forest types. This suggests that the preponderance of multi-story evergreen forests in the Western Ghats is a function of micro-climate defined by temperature, precipitation along with other physical parameters such as altitude, slope, wind direction and speed, geology and most importantly the anthropogenic pressures. The changes in the physical parameters in terms of thresholds could change the composition of the forests and it would alter the distributional patterns of the individual species. Similarly, the conducive or unfavourable physical parameters would allow the given ecosystem to expand more or reduce in size.

To understand such possibilities in the context of the forests and biodiversity at large in Maharashtra we have mainly relied upon the secondary literature and the hands on experience of working in different ecosystems in Maharashtra and other parts of India. In the context of Maharashtra there are specific areas known for higher species richness and other ecological importance identified by various processes for the purpose of biodiversity conservation. But all these areas lack the long term monitoring data for understanding the changes over period. And at this point of time these areas have been studied for their biodiversity significance. The plant ecological studies have attempted to understand some of the aspects of the temperature and precipitation tolerance of habitats of evergreen, deciduous forests. The biogeographical studies of distribution ranges of species and the altitudinal preferences are of importance to understand the impacts of the climate change. Hence, due to the absence of the monitoring mechanisms for various ecosystems along with temperature, precipitation, etc. there is a need to qualitatively understand the impacts on the biodiversity with respect to the possible future variability in the parameters responsible to shape up the biodiversity.

Thus, in this chapter we have attempted to understand the geographical classification of the state mainly driven by the historical administrative and geo-physical characteristics, identification of important high biodiversity value areas in the context of climate change.

Based on the available work done towards understanding the impacts of climate change on forests and biodiversity, possible changes in physical parameters such as temperature, precipitation, etc. a qualitative analysis is performed to undertake possible measures for adaptation and mitigating the impacts of climate change on the forests and biodiversity of the state.

11.2 Overview of geographical classification of Maharashtra

The State of Maharashtra is generally divided into five major regions locally referred as Konkan, Khandesh, Western Maharashtra, Marathwada and Vidarbh. These regions not only differ in terms of their historical administrative conditions but also have distinct features shaped due to geo-climatic conditions which are largely responsible for the manifestation of biodiversity in the respective regions.

Konkan – It is a coastal strip of about 750 km long and 27-48 km broad running along the west coast of Maharashtra. The average height of the coastal strip is about 6-9 m from mean sea level and the region also covers the hill chain on the western slopes of the Western Ghats which rarely rise above 400 msl. The region receives high rainfall generally above 2000 mm and enjoys the maritime climate with higher relative humidity. The coastal strip of 15-17 km is a marshy saline bed due to incursion of sea which encourages only salt tolerant plants. The land beyond the saline strip is generally made up of alluvial soil with fertile nature. The soil has low water retention capacity.

Khandesh – It lies in the valley of the Tapi river located between Ajantha and Satpuda ranges and separated from western Maharashtra by the Laling and Silvari hills. The region receives poor rainfall and suffers extreme climatic conditions with winter being very cold and summers hot. Soils are alluvial and black cotton. Toranmal plateau at a height of 1009 msl is one of the highest points in Khandesh with biodiversity importance.

Western Maharashtra – The region is identified by hot and dry climate with the average rainfall ranging between 600-700 mm with poor humidity. It has the highest peak named Kalsubai at 1646 msl. The soils are alkaline or black cotton type. The river valleys have alluvial soil composition. The soils in *Mawal* are lateritic and gravelly in nature. The forests in this region are marked by poor soil depth.

Marathwada – The hot and dry climate marked by poor and uncertain rainfall ranging between 500-600 mm and predominantly unfertile soil. The banks of Godavari river has alluvial fertile soils. The monsoon flora has been characterized by the large number of ephemerals.

Vidarbh – The region stands on an upland plateau of 457-548 msl. It consists of Deccan trap basal giving rise to black cotton soils. The region receives rainfall in a range of 790 to 1470 mm. The region is marked by hot and dry climate touching 47^0C during summers. The large parts of Vidarbh are under dense deciduous and semi-evergreen forests.

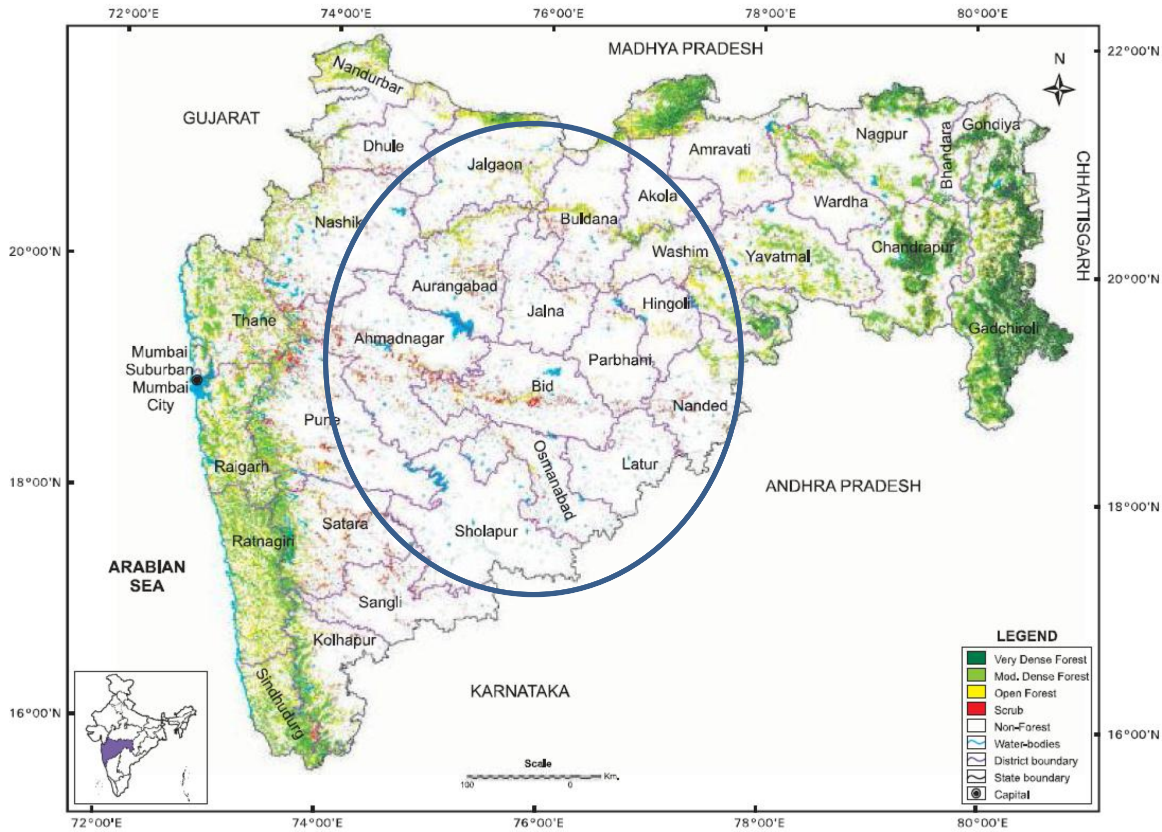
This classification of the state is mainly based on the socio-political phenomenon and to an extent the climatic conditions. But there are also overlaps between these regions like central parts of the State comprising of parts of Western Maharashtra and Marathwada share similar climatic conditions extending upto western Vidarbh.

The distribution of forests and biodiversity is certainly a product of the prevailing climatic features of these various regions of Maharashtra where the various mountain ranges namely Sahyadri, Satpuda, Mahadev harbouring the forest dominated ecosystems and the Deccan trap dominated other regions being predominant with grasslands and woodland savannas.

The Western Ghats which is also referred as Sahyadri has been recognized as one of the Biodiversity Hotspots. The ecosystems in the northern Western Ghats are of important biodiversity value. The northern ranges of the Sahyadri (15°30′–20°30′N lat., 73°–74°E long.), lie in Maharashtra. The vegetation is more or less in the form of fragmented patches in contrast to continuous stretches of forests in SWGs. Presence of numerous barren, rocky, lateritic plateaus, locally known as 'sadas', is a unique feature of the NWGs. It supports characteristic ephemeral flush vegetation harbouring monotypic genera, many of which show restricted or narrow distribution. However, it is impoverished on account of overall woody species richness, one of the reasons being absence of species rich forest types, such as *Myristica* swamps and shola forests that are unique to the Southern Western Ghats (SWG) (Kanade et al 2008). The soil composition and composition of the substratum rock provides an important basis for the differences in the vegetation composition and structure apart from other parameters such as precipitation regime. Though the ecosystem like *Myristica* swamps is a common feature of SWG, the ecosystem is also found in parts of Sindhudurg district where the geological characteristics differ from the northern districts.

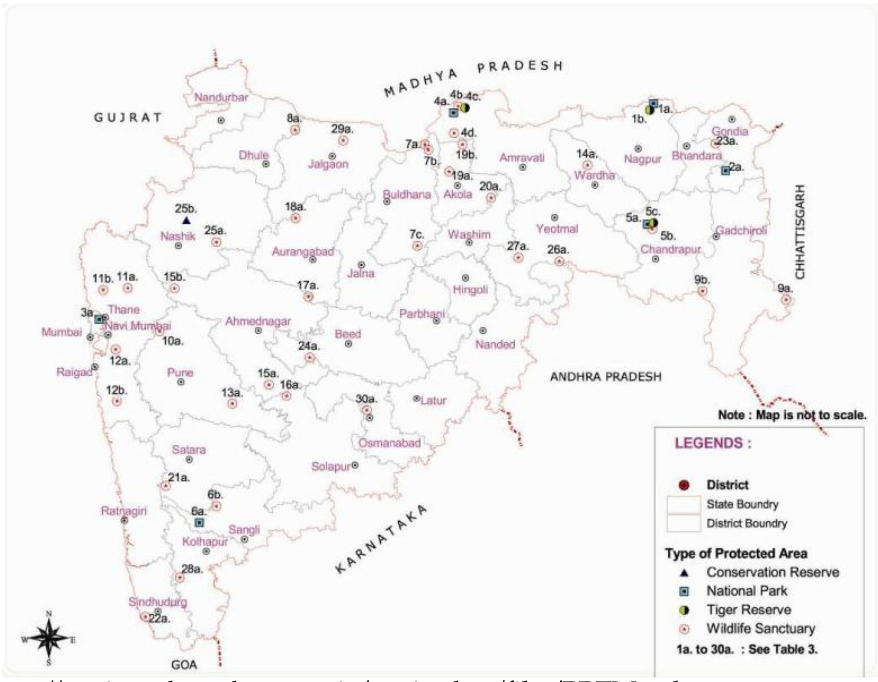
11.3 Distribution of biodiversity and protected area network in Maharashtra

The available information regarding distribution of biodiversity in Maharashtra State is highly biased towards the forest ecosystems which is about 16.46% of the state's area and large are of the state is considered as non-forest land. The following map prepared by Forest Survey of India (2011) shows the distribution of forests and non-forest areas in the state but it fails to capture the other ecosystems such as grasslands and woodland savanna which constitute substantial part of Khandesh, Marathwada, western parts of Western Maharashtra, and eastern Vidarbh as depicted by the circular boundary on the map. And the coastal strip running about 750 km constitute the important habitat for mangroves, salt marshes, fisheries and corals.



Source: Forest Survey of India 2011

Figure 1: Distribution of forests, woodlands and grasslands in Maharashtra



Source: http://envis.maharashtra.gov.in/envis_data/files/PRTMap.htm

Figure 2: Location of protected areas in Maharashtra

Wildlife conservation in Maharashtra is enabled through a network of 33 wild life sanctuaries and five national parks as shown in the above map.

Apart from these measures taken by the state government for the conservation of biodiversity, there have been attempts to prioritise areas of special biodiversity importance in form of Wildlife Sanctuary (WS), National Park (NP), Important Bird Area (IBA), Biodiversity Hotspot, etc. as compiled in the table below. The categories WS and NP are the protected areas identified and managed by the forest department, IBAs have been identified by Bombay Natural History Society (BNHS) in a consultative mode with various national and international institutions, Biodiversity Hotspots have been identified for the Western Ghats of Maharashtra by a NGO Research and Action and in Natural Wealth Administration (RANWA) under the Biodiversity Hotpot Conservation Programme of WWF-India. The exercise done by Critical Ecosystem Partnership Fund and ATREE has identified specific pockets in the Western Ghats for conservation importance (Appendix 1).

These prioritised locations offer a subset of forests and biodiversity locations having specific importance for conservation due to endangered / threatened habitats and species, possible impact due to climate change, biogeographical importance, etc. Such kind of prioritization has helped to generate information regarding these sites but large areas still face the limitation of under-explored status for their biodiversity importance. Hence, there is a need to not only restrict to these sites but also to take into consideration the similar habitats using the techniques such as GIS-Remote Sensing. Also there is a need to take into account the anecdotal records of observations recorded by the naturalists such as sighting of Lesser Florican in grasslands of near Karanja, Akola district after several years.

The distribution of vegetation in Maharashtra has unique characteristics mainly defined by the different climate regimes.

11.3.1 Distribution of Evergreen forests in the Western Ghats

The forests of the Western Ghats are unique in the world for various reasons. There region on of the 34 hot-spots of biodiversity in the world. The region is famous for one of the highest levels of endemism of plants. The vegetation in the region has affinities with the vegetation in the south-east Asia in terms of families and also genera of plants in spite of substantial difference in the rainfall and the number of rainy days available in the Western Ghats. The region roughly lies between 15^0 54'N to 20^0 30'N and 73^0 E to 74^0 E measuring about 42000 km^2 with a width of about 60-80 km and north to south length of about 5—km. It covers Raigar, Ratnagiri, Sindhudurg and Thane districts entirely along with parts of Ahamadnagar, Kolhapur, Nashik, Pune, Satara and Sangali.

The entire vegetation in the region is considered as 'Tropical Moist' type. But the altitude and the Latitude-Longitude position of the given location defines the nature of the local vegetation which varies from primarily evergreen to semi-evergreen. The vegetation type in the Western Ghats region is defined by number of rainy days or annual dry period, altitude, topography, soil type and the most important anthropogenic influence. These parameters constitute the climatic climax of the vegetation (combination / co-association of various dominant species) of any given locality. The evergreen forests also need a classification in terms of primary evergreen and secondary evergreen forests considering the possible historical anthropogenic impacts.

The zoning of the primary evergreen forests based on the combination of dominant species with respect to the altitudes could be describes as follows –

a) *Cryptocarya wightiana – Drypetes venusta – Garcinia talbotii – Litsea stocksii* type of higher elevation **(700m-800m to 1100-1200m Above Sea Level)** vegetation type. It is accompanied by locally dominant species combination such as *Mangifera indica, Dimorphocalyx lawianus* at Bhimashankar, *Syzygium heyneanum, Dimicarpus longan* at Koyna, Chandoli, and *Syzygium hemisphericum* at Radhanagari and Amboli.

b) *Dimocarpus longan- Holigarna grahamii* type of medium elevation **(500m-600m to 700m-800m Above Sea Level)** as found at Varandha

c) *Holigarna arnottiana-Lophopetalum wightianum* type of low elevation **(from mean sea level to 300m-500m)** as found at Sawantwadi.

The secondary evergreen forests at the medium and high altitude are dominated by *Memecylon umbellatum – Syzygium cumini – Actinodaphe angustifolia* type. At lower altitudes the secondary forests turn into moist deciduous forests.

11.3.2 Distribution of Semi-evergreen forests

The semi-evergreen forests are found on the western slopes upto about 600 m whereas on the eastern slopes they are found upto 800m altitude. These forests are dominated by species such as *Mammea suriga, Putranjiva roxburghii, Terminalia tomentosa, Terminalia paniculata, Holoptelia integrifolia, etc.*

11.3.3 Distribution of Moist and dry deciduous forests

The zonation of deciduous forests in Maharashtra is mainly determined by the extent of rainfall and the number of rainy days. The Gadchiroli district with higher rainfall has luxuriant moist deciduous forests as against the northern district of Gondiya which is dominated by the dry deciduous forests. The temperature regime would also be considered as one of the important parameters of species composition for deciduous forests.

11.3.4 Distribution of savannah grasslands

The major portion of Maharashtra where the geological foundation is Deccan Trap is predominated by the savannah grasslands and the thickets. This ecosystem is largely driven by the extensive dry months (about 8-9 months) and low rainfall during the monsoon. The region gets classified as semi-arid. The region is known for the important bird species such as Lesser Florican, Great Indian Bustard and animal species such as Wolf and Chinkara.

11.4 Forest degradation in Maharashtra due to non-climatic parameters

The forests and biodiversity in Maharashtra have been plagued with the issues of deforestation and forest degradation. The information collected by Forest Survey of India, several independent studies have raised the concerns of the forest degradation.

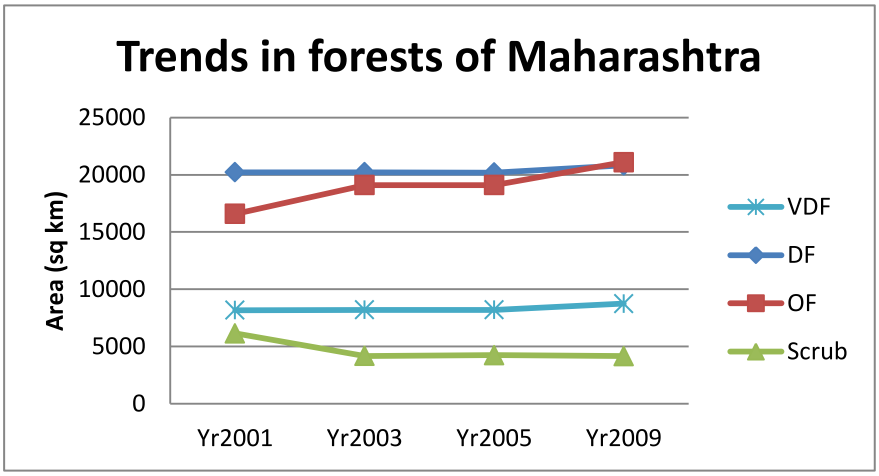


Figure 3. Trends in forest area of Maharashtra

Source: Forest Survey of India data

Panigrahy et al (2010) have analysed the changes in the forest cover and other landuse specifically for the Western Ghats of Maharashtra. The study suggests that there has been a decrease in the dense forest by more than 10% in the Western Ghats and increase area under the waterbodies. The district wise patterns of the changes in vegetation are important in correlating with the ongoing developmental processes.

Table 1 Change in forest class area (statistics from 1985-87 to 2005)

	1985–87	2005	Change (%)	Difference (sq. km)
Dense forest	5,771.24	5,161.01	−10.57	−610.2
Open forest	3,892.30	4,239.24	8.91	346.9
Highly dense tree farm land	912.87	862.93	−5.47	−49.9
Less dense tree farm land	2,636.32	2,665.11	1.09	28.8
Mangrove	93.41	172.95	85.15	79.5
Scrub-lands	3,911.10	4,104.19	4.94	193.1
Water bodies	1,199.44	1,681.33	40.17	481.9
Forest blanks/grassy lands/permanent cultivation	76,737.25	76,321.50	−0.54	−415.7
Un-interpreted area/gaps/clouds/hill shadows	69.97	15.66	−77.62	−54.3
Forest	17,217.24	17,207.042	−0.06	−10.2
Non-forest	77,936.69	78,002.83	0.085	66.1
Total	95,223.90	95,223.90		

Area values in square kilometer unit.

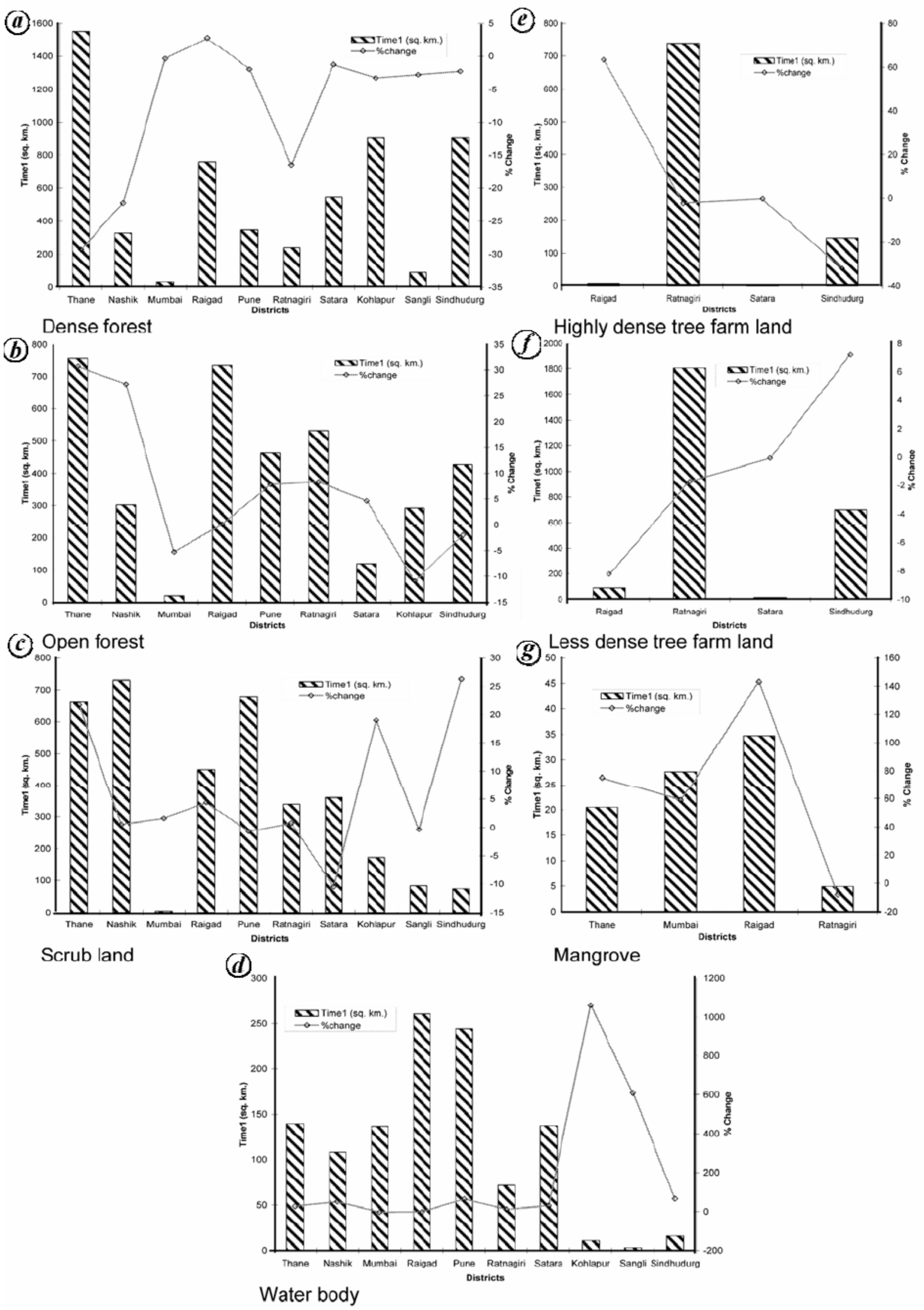


Figure 4 District wise change (%) in vegetation classes from time 1 to time 2.

The decrease in the area of dense forest and increase in open forest and scrublands are indicators of pressure on the core forest. A study of fragmentation trends may further reveal the loss of corridors. The increase in water bodies (including dams) probably to cater the needs of the growing population has altered the ecosystem (Panigrahy et al 2010).

The use of satellite imageries for comparing the status of forests have always been limited due to number of reasons e.g. FSI data does not have qualitative approach for ecosystems like evergreen forests where the species composition forms an important aspect to recognize change whereas in the independent studies, the temporal dimension is missing since most of such studies are single attempt studies. Also differences in the classification approaches of the satellite data of different studies limit the wider applicability of the analysis. But with all these limitations in mind the two studies mentioned above point out the increase in the open forests and decrease of evergreen forests in the Western Ghats.

The continued dependence of the local communities on firewood and grazing on the natural ecosystems has also been responsible for degrading the habitats. The villages on the fringes of the protected areas are and the remote villages located on the fringes of other important ecosystems beyond the boundaries of the protected areas need a special attention in this regard.

The regeneration of evergreen plant species is linked with the nature of seed dispersal mechanism and availability of the given mechanism or vector. It is found that there is a tendency for evergreen species to be zoochorous (dispersed by animals), and for deciduous species to be anemochorus (dispersed by wind) - or autochorous (dispersed by plant itself) (Tadwalkar et al 2012). The habitats for small animals have been getting restricted to the protected areas and which would hamper the regeneration of the evergreen species in the southern Western Ghats outside the protected areas because of lack of seed dispersing agents.

11.5 Impacts of climate change on forests and biodiversity

The assessment of future climate change done by Chaturvedi et al 2011 is based on climate projections of the Regional Climate Model of the Hadley Centre (HadRM3) and the dynamic global vegetation model IBIS for A2 and B2 scenarios.

The vegetation distribution simulated by IBIS for baseline, A2 and B2 scenario in the forested grids suggests that there is an expansion of tropical evergreen forests (IBIS vegetation type 1) in the Western Ghats. Further, there is a slight expansion of forests into the western part of central India. Overall, there is negligible difference between forest extents predicted for the future in the A2 and B2 scenarios except that forest expansion is higher into the western part of central India in the A2 scenario. This could be attributed to higher precipitation levels in A2 scenario relative to B2 in this region. One caveat to the expansion trend of forests (like tropical evergreen) is the assumption that forests are un-fragmented, and there is no dearth of seed-dispersing agents. In the real world, forests are fragmented, and, seed dispersal may not be efficient in the view of loss or reduction in number of dispersal agents due to human habitation pressures and climate change. As the population of seed-dispersing agents may decline, predicted forest expansion is not guaranteed (Chaturvedi et al 2011).

Northern and central parts of the Western Ghats seem to be vulnerable to climate change. Northern parts of the Western Ghats contain significant extent of open forests, which drive up the vulnerability score. High values of the index in the central part of the Ghats are likely caused by the negligible precipitation increase over there (with more than 3°C rise in temperature).Forests in the southern Western Ghats appear to be quite resilient as forests in this region are less fragmented, more diverse and they also support tropical wet evergreen forests which, according to IBIS simulations, are likely to remain stable. The analysis suggests that Western Ghats, though a bio-diversity hotspot, has fragmented forests in its northern parts. This makes these forests additionally vulnerable to climate change as well as to increased risk of fire and pest attack. Similarly, forests in parts of western as well as central India are fragmented. Forests are likely to benefit to a large extent (in terms of NPP) in the northern parts of Western Ghats and the eastern parts of India, while they are relatively adversely affected in western and central India. This means that afforestation, reforestation and forest management in northern Western Ghats and eastern India may experience carbon sequestration benefits. Hence, in these regions, a species-mix that maximizes carbon sequestration should be planted. On the other hand, in the forests of western and central India, hardy species which are resilient to increased temperature and drought risk should be planted and care should be taken to further increase forest resilience. This may be achieved by planting mixed species, linking up forest fragmentations, devising effective pest and fire management strategies and carrying out anticipatory plantation activities (Chaturvedi et al 2011).

Precipitation and temperature have been two important climatic parameters which have been decisive in determining the trends in the forest ecosystems. Various modelling studies have depicted possible changes in these two parameters which would result into possible changes in the species compositions, Net primary Productivity (NPP)of the ecosystems and so on. Following are important finds from few modelling efforts in order to understand the impacts on the forest ecosystems.

INCAA report

Precipitation

Coastal Region- West coast – The increase in rainfall is by 6 to 8 %, an increase that is ranging from 69 to 109 mm. Though June, July and August show an average increase of 8mm rainfall in 2030's with respect to 1970's, however, the winter rainfall is projected to decrease on an average by 19 mm during the period January and February in 2030's with reference to 1970's. The period March, April and May also show a decrease in rainfall with respect to 1970's.

Extreme Precipitation

The intensity of the rainy days increases in a more warming scenario in Q14 with respect to simulations Q0 and Q1. However Q14 simulation suggests decrease in the intensity of rainy days over Western Ghats

Mean annual surface Temperature

West coast: The annual temperatures are set to increase from a minimum of 26.8°C to a maximum of 27.5°C in the 2030's. The rise in temperature with respect to the 1970's correspondingly ranges between 1.7 to 1.8°C. Temperatures are also projected to rise for all seasons for all the three simulations from 1.5 to 2.2°C with the rainfall period of June, July, August and September showing the minimum rise amongst all seasons.

Extreme Temperature

The spatial pattern of the change in the lowest daily minimum and highest maximum temperature suggests a warming of 1^0 C to 4^0C towards 2030's. The warming in night temperatures is more over south peninsula, central and northern India, whereas day time warming is more in central and northern India.

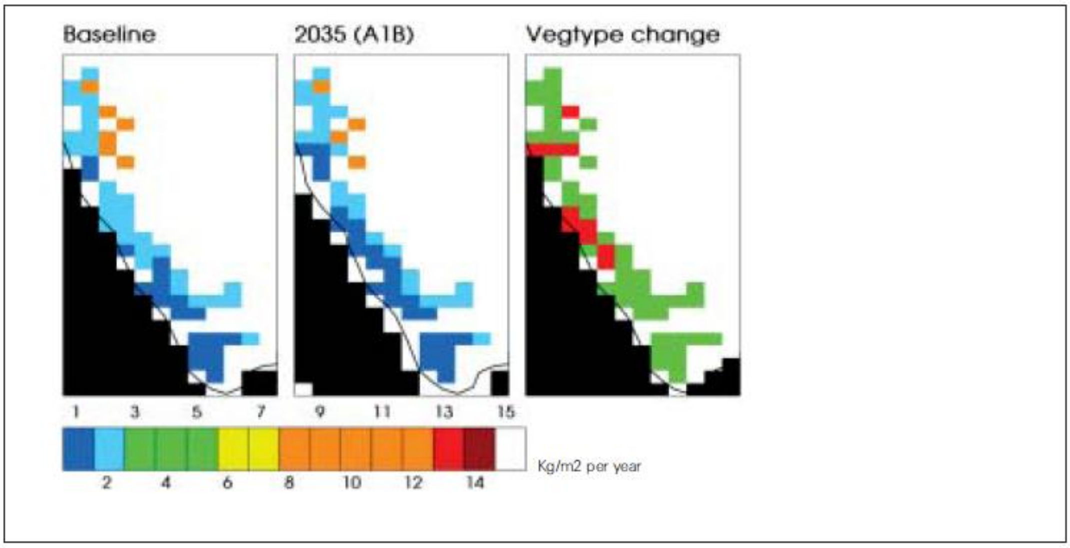


Figure 5 Simulated dominant vegetation in the Western Ghats region for the baseline (left panel) and 2035 (middle panel). The grids where a change in vegetation is projected are shown in red in the right panel

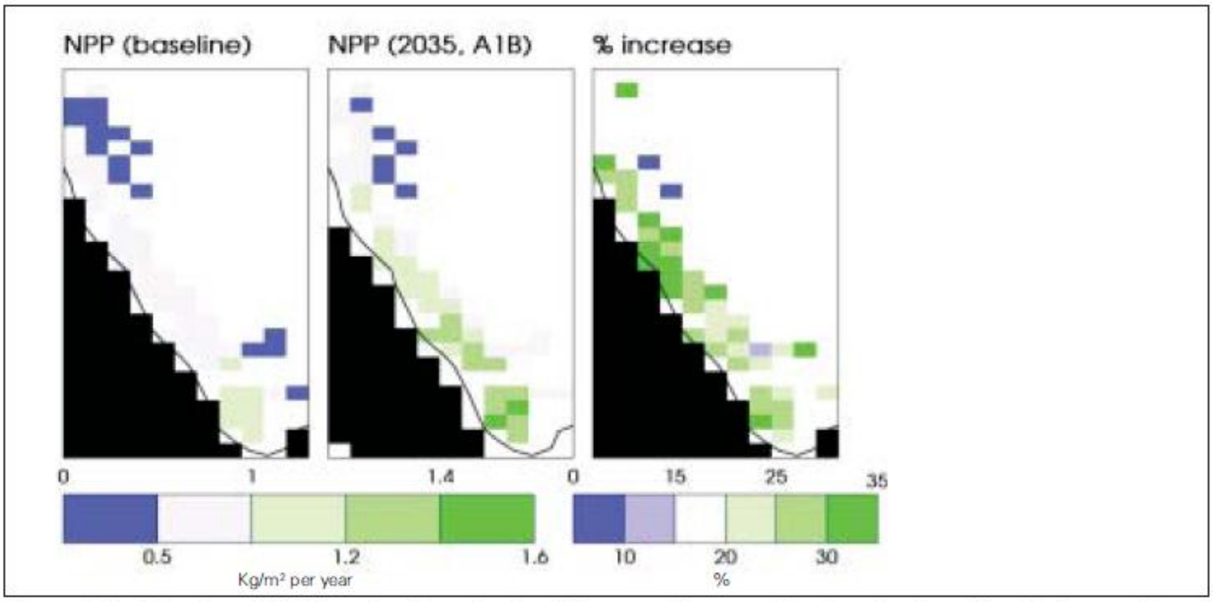


Figure 61 Simulated NPP projections in the Western Ghats region for the baseline (left panel) and 2035 (middle panel). The projected percent increase in NPP is shown in the right panel

In the Western Ghats 18% forested grids in the region are projected to be vulnerable to climate change. The region is projected to have approximately 20% increase in NPP on an average.

TERI modeling results on temperature, precipitation and Land use – Land cover

The detailed results of the modeling done by TERI have been communicated and in the context of forests and biodiversity some the results have reiterated as follows –

Precipitation

The ensemble mean rainfall is able to capture the rain shadow region reduction in rainfall, the high rainfall variability over the Western Ghats region and also on the eastern parts of Maharashtra.

Temperature

Annual Mean temperature is found to be 1.2-1.5 degrees centigrade increase in the Vidharbha region, Marathwada and Nasik regions as compared to Pune and Konkan region where the increase in temperature was found to be 1- 1.2 degrees centigrade.

Land use and Land cover changes

A predictive modeling assessment of changes in land use and land cover was undertaken with several independent variables that included (i) social agents of change namely proximity to road, and proximity to settlement, (ii) topographic agents of change namely proximity to water, elevation, slope, aspect and dependent variables of the change in the forest cover and land use in past decades. Population pressures have largely driven the trends in the predictions. In addition to this, the accessibility variables that are development driven were given more importance than the topographical ones and socio-economic land use practice and conversion of land to permanent agriculture have also been considered as they play an important role in changing landscape as underlying driving forces of forest cover changes. These assessments were done for the baseline years 1998, 2005 and 2012 as well as for the future for the year 2030.

The results as shown in the Figure 7 suggest that the fragmentation of forests in the northern Western Ghats has been increasing due to urban and rural settlements and the scenario continues for 2030, 2050 and 2070 situation.

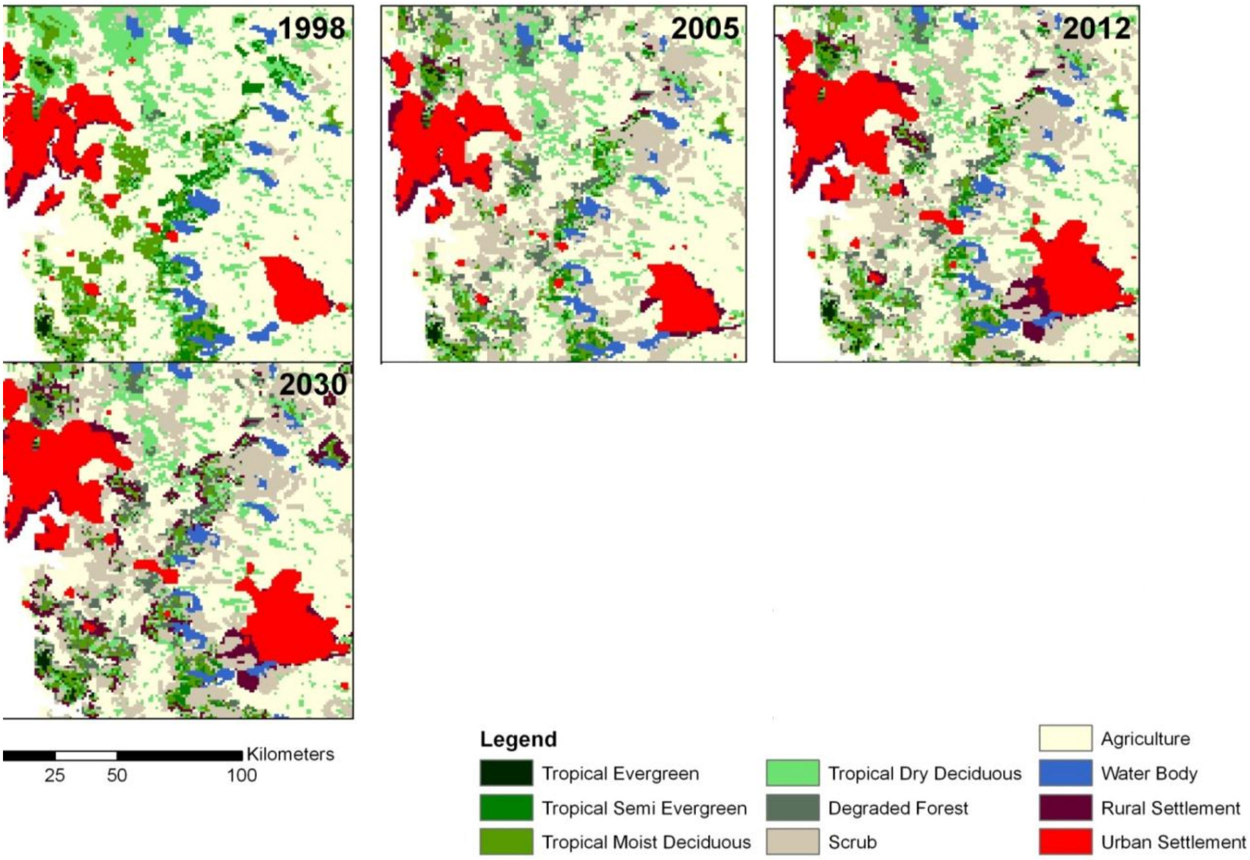
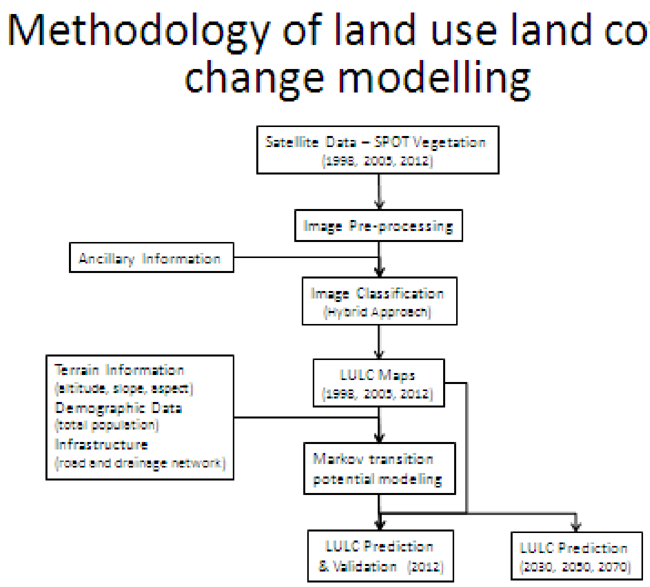


Figure 7: Fragmentation captured by land use land cover model for parts of the Western Ghats

These results have been generated based on the following methodology –



11.6 Prioritising vulnerability and risks for ecosystems

The analysis of various studies suggests that the forests of the northern Western Ghats have been getting degraded over decade with substantial decrease in the dense forests. Similarly, there has been higher degree of fragmentation observed in the northern Western Ghats making the region less resilient to the impacts of climate change in comparison to the southern Western Ghats. This suggests that there is a need to conserve more effectively the patches of southern part of Sahyadri which have more resemblance with the southern Western Ghats vegetation. The northern portion of the Sahyadri is getting more fragmented and hence need more measures of building corridors and assisting the natural regeneration.

The general trend in the precipitation suggests that for the Sahyadri there would be increased rainfall with reducing number of rainy days. The various stages of climax evergreen forests in Sahyadri are extremely sensitive to the increased temperature regimes and reduced soil moisture. Such localities need to be monitored to understand the impacts on the regeneration patterns. It would provide the information about the possible loss of the certain set of species and would also reveal the thresholds of temperature and precipitation for a range of species and the respective habitats.

The reducing rainfall and the increasing temperature on the Khandesh, Marathwada and eastern Vidarbh would possibly result into increasing aridity and reducing the fodder availability. To contain these impacts intensive soil and water conservation measures would be needed. The forested regions of northern and southern Vidarbh would possibly behave differently where semi-evergreen to moist deciduous forests in southern part would turn into moist deciduous to dry deciduous and the dry deciduous forests in the north would possibly turn into more hardy woodlands.

It should be noted that the impact of the climate change is possibly increasing the vulnerability of the existing vulnerable elements of biodiversity like evergreen forests of northern Sahyadri and in addition to that there have been additions of new vulnerable areas like moist deciduous forests of southern Vidarbh.

Following table provides an overview of the anticipated impacts due to climatic and non-climatic factors on the terrestrial ecosystems of Maharashtra. The table also identifies the vulnerable elements, the priorities for scientific research and the possible adaptation measures.

Table 2 Region-wise impacts of climate change on ecosystems in Maharashtra

Sl No.	Region	Ecosystems	Non-climatic Drivers	Climatic drivers	Anticipated impacts by 2030 to 2070	Vulnerable elements	Adaptation measures	Scientific priorities	Suggested areas (Refer Annexure- 1)
1	Western Ghats / Sahyadri	Tropical evergreen forests, Tropical Semi-evergreen forests	Development, Land use change to non-forest	Increase in Precipitation by 10% to 30% with reduced number of rainy days, temperature increase between 1 to 4 deg C	Increased fire risks, fragmentation, possible conversion of forests to savanna woodlands and pest attacks, in northern WG. Threat to dense forests in southern WG. Reduced regeneration due to hampered seed dispersal	Primary and Secondary evergreen forest patches	afforestation, reforestation (mixed species focussing on C sequestration models), building corridors in northern WG and forest conservation measures for southern WG, In-situ and Ex-situ conservation	Monitoring and conservation of vulnerable habitats and climatic thresholds of endangered flora and fauna	1, 2, 4, 5, 7, 8, 9, 12, 14, 17, 32, 33
2	Konkan	Tropical Semi-evergreen forests	Development, Land use change to non-forest	Increase in Precipitation by 10% to 30% with reduced number of rainy days, temperature increase between 1 to 4 deg C	Increased fire risks, fragmentation and pest attacks, in northern WG. Threat to dense forests in southern WG. Reduced regeneration due to hampered seed dispersal	Tropical Semi-evergreen forests	afforestation, reforestation (mixed species focussing on C sequestration models) in northern parts and forest conservation measures for southern parts, In-situ and Ex-situ conservation	Monitoring and conservation of vulnerable habitats and climatic thresholds of endangered flora and fauna	2, 3, 6, 11, 13, 15, 20, 28, 29, 31
3	Khandesh	Tropical Dry Deciduous forests, Savanna woodlands	Anthropogenic pressures	Substantial rainfall increase, increasing temperature, higher chances of extreme rainfall events	Increased aridity and reduced fodder supply, change in forest type from dry deciduous to savanna woodlands	Tropical dry deciduous forests	afforestation, developing alternatives for firewood, fodder, exploring alternative technology based solutions	Monitoring and conservation of vulnerable habitats and climatic thresholds of endangered flora and fauna	16, 23, 25, 27, 30

4	Marathwada	Savanna woodlands, Scrubs and Grasslands	Anthropogenic pressures	Increasing rainfall, increasing temperature	Increased aridity and reduced fodder supply	Grasslands, Rare bird species such as Lesser Florican, Great Indian Bustard and endangered animals such as Chinkara	afforestation, developing alternatives for firewood, fodder, exploring alternative technology based solutions, strategies for conservation of grasslands and associated flora and fauna, In-situ conservation,	Conservation measures for endangered fauna	18, 19
5	Vidarbh	Tropical Dry and Moist Deciduous forests, Scrubs, Grasslands	Anthropogenic pressures, land use change	Increasing rainfall, increasing temperature, extreme heat waves	Increased aridity and reduced fodder supply, change in forest type from dry deciduous to savanna woodlands	Grasslands, Rare bird species such as Lesser Florican, Great Indian Bustard and endangered animals such as Chinkara	afforestation, developing alternatives for firewood, fodder, exploring alternative technology based solutions, strategies for conservation of grasslands, moist deciduous forests and associated flora and fauna, In-situ conservation,	Monitoring of vulnerable habitats and climatic thresholds of endangered flora and fauna, Conservation measures for endangered fauna	21, 22, 24, 26

Thus the main risks which could be summarised from table 2 are as follows –

a) Fragmentation of habitats – Due to fragmentation the habitat specific species especially from evergreen forests are threatened.

b) Lack of data and monitoring of habitats – There has been a serious lack of data to visualise uunforeseen risks of changes in species distribution due to lack of understanding in thresholds of temperature and precipitation at ecosystem/species levels, lack of monitored data over a period of time from selected area, etc.

c) The changes in temperature and precipitation would form an additional risk for number species of flora and fauna which are currently under threat such as Chinkara, Lesser Florican, etc.

11.7 Climate change impacts on mangroves in the State

Mangrove habitats are likely to be more vulnerable to climatic changes and resultant sea level rise (SLR) because of their unique location at the interface of the sea, by altering eco-biological processes.

Impacts of climate change on mangroves include;
1. Impacts caused by change in Sea Level Rise: Forest cover and productivity of mangroves is likely to be affected by a rise in sea level. Sea-level rise may extend the intertidal and supra tidal zones further inland resulting changes in existing ecological set up. However, the ability to migrate both in the landward and seaward side maybe limited by conditions such as roads, agricultural fields, seawalls, shipping channels and topography like steep slopes. Restrictions on the landward margin may result in water logging, killing mangrove trees and their associated biota.
Studies have shown that mangroves may be able to keep pace with a Sea Level Rise of 8-9 cm/ 100 years, but would be stressed at rates between 9-12 cm/ 100 Yrs and may neither grow nor form peat at rates of SLR of 12 cm/ 100 Yrs. When sedimentation rates cross 12 cm per 100 years, mangroves may undergo physiological stress caused by pneumatophore choking that may result in their demise.

2. Impacts caused by change in frequency and levels of high water events and storm events may impact the health of mangrove ecosystems. Studies have shown that storms alter sediment elevation and sulphide soil toxicity in mangrove ecosystems. Extreme storms may also reduce recruitment and sediment retention, impact forest growth and thereby cause a decrease in forest cover. Increased intensity and frequency of storms may also cause defoliation, tree mortality, stress and may increase damage to mangrove forests.

3. Effects of changes in temperature may impact photosynthesis, water loss, transpiration and salt loss. Temperatures greater than 35 °C result in thermal stress that impacts root structures and the establishment of seedlings, and at temperatures crossing 25 °C, a decrease in leaf formation rates has been observed. Increased sea surface and air temperatures are likely to reduce productivity at low latitudes. Temperature changes may also result in

changing species composition, phonological patterns expanding mangroves to higher latitudes, when other factors are not limiting.

4. Altered ocean circulation patterns may affect mangrove dispersal and gene flow of mangrove forests thereby causing changes in community structure.

5. Effects of increase in carbon dioxide concentration may increase photosynthetic levels and therefore mangrove growth rates. Increased concentrations may also result in efficient regulation of water loss and change in vegetation along natural salinity and aridity gradients.

6. Changes in UVB radiation is likely to change the morphology, photosynthesis and productivity of mangrove ecosystems.

7. Changes in precipitation are likely to impact distribution patterns and growth of mangroves. Decreased rainfall and increased evaporation will result in an increase in salinity, a decrease in net primary productivity, growth and seedling survival, change competition between mangrove species, decrease diversity, ad decrease mangrove area by changing upper tidal zones to hyper saline flats. An increase in soil salinity will result in increased tissue salt levels in mangroves and decreased water availability resulting in reduced productivity. Salinity increases will also increase sulphate availability in seawater, increasing anaerobic decomposition of peat and increasing the vulnerability of mangroves to sea level rise. Increased rainfall will result in increased growth rates and biodiversity, increased diversity of mangrove zones, an increase in mangrove area and the colonization of previously barren areas of the landward fringe (in the tidal wetland zone).

11.8 Adaptation needs and priorities

To summarize, tropical semi-evergreen forests, tropical moist deciduous forests and tropical dry deciduous forests have decreased over the period 1998-2012. If business-as-usual trends continue, there will be degradation of forests and fragmentation in the northern Western Ghats and loss of biodiversity corridors, which will make the region less resilient to the impacts of climate change. The risks presented by climate change for key species that are already vulnerable due to loss of habitat and other anthropogenic threats. The key impacts of climate change on ecosystems in Maharashtra are:

- Increased fire risk in savanna woodlands of Northern Western Ghats and Northern Vidarbha due to higher temperatures and arid conditions
- Increased aridity and reduced fodder supply in Marathwada, Khandesh, and Vidarbha.
- Local species loss especially of mangroves, fishes & associated biota due to increased salinity of water
- Longer term threats (by 2070s) to endangered species and ecosystems due to poor regeneration of species (Tropical evergreen forests of Western Ghats), habitat

reduction for faunal species such as Chinkara, Maldhok (Bustard), Tanmore (Florican), etc. (Grasslands of Marathwada, Khandesh, Vidarbha).

- Longer term changes (by 2070s) in composition and quantum of fish landings and impacts on associated livelihoods

Table 2 also identifies three main priorities to address the adaptation against the climate change as follows –

a) Biodiversity conservation
b) Developing buffers
c) Scientific monitoring and research

11.8.1 Biodiversity Conservation

The conservation of specific habitats needs to be the focus of the biodiversity conservation efforts. The areas which are the last refuge – ecological refugia for the species need a careful conservation measures. The conservation hence needs to be considered to protect and manage the biodiversity, assist the natural regeneration of key species in the respective habitats along with the use of *ex situ conservation* measures for flora and fauna.

Some of the important habitat types for conservation are primary Tropical Evergreen and Semi-evergreen forests in the Western Ghats. It should be noted that the forests of southern Western Ghats and northern Western Ghats in Maharashtra have different priorities where the southern region needs more attention for enhancing pollination, seed dispersal and thus aiding the regeneration of the species. The northern part of the Western Ghats is faced with the challenge of fragmentation and ecological isolation and to tackle this there is a need of developing corridors for conservation of remaining patches of the evergreen forests. The assisted natural regeneration needs to be used to strengthen the degraded habitats and the introduction of the species needs to be based on the identification of the process of the ecological succession and the available associate species. This activity has been extremely important to link the fragmented patches by developing corridors for species migration.

The conservation of species such as Lesser Florican, Great Indian Bustard, Chinkara which require grassland dominated systems need to be understood with respect to the spread of habitats beyond the administrative boundaries of the State Forest Department with participatory approach involving the local people.

Apart from these specific measures suggested there could extension of the already existing programmes such as Annual Recovery Plans for the Great Indian Bustard, Lesser Florican by the centrally sponsored scheme of MoEF Integrated Development of Wildlife Habitats (CSS-IDWH). In fact there is a need of participatory approach for conservation of Bustard species going beyond the boundaries of the State Forest Department since the habitat is shared even outside the officially designated protected areas.

In addition to such specifically identified measures at the respective sites, Annexure – 1 identifies the list prioritized sites for implementing the adaptation measures. The Table ( ) provides the region-wise identification of sites for respective set of activities.

11.8.2 Developing buffers

The continued pressure of the local communities on the forests for basic needs such as firewood, grazing needs to be tackled by developing buffer areas to be specifically managed for such subsistence needs. Along with developing the buffers the alternative technology for fuel, substitutes of fuels could be provided to the local communities for halting the further degradation of habitats.

The firewood and the fodder demands need to be addressed by developing the suitable plantations. The priority of the firewood and fodder could be targeted around the protected areas in the state. Along with the buffer plantations the alternative technologies such as improved stoves, biogas (where there is sufficient supply of cow dung) could be implemented.

The development and conservation of corridors has to be the focus for the evergreen forest patches in the northern Western Ghats. There has been identification of important areas in the region and a sample can be seen in the Annexure -1.

The prevention of forests and grasslands from fire has also been an important activity needs to be done carefully. The deciduous forests such as Navegaon, Nagzira suffer heavily due to the forest fires impacting the biodiversity. There is a need to understand the fire dynamics and accordingly use the strategies such as fire lines, early burning, etc.

11.8.3 Scientific monitoring and research

The prescriptions for specific measures to tackle the impacts of climate change on biodiversity are constrained by the availability of the information such as thresholds of the species with respect to temperature, precipitation, etc. Hence, there is a need to generate the threshold data for various habitat types such as evergreen forests, moist deciduous forests, deciduous forests, grasslands, etc. Similarly for some of the indicator plant species such information needs to be generated by establishing data loggers or other methods. Monitoring experiments should be undertaken for various forest types by establishing the long term monitoring plots. In the Western Ghats of Maharashtra already there exist a limited network of small plots mainly at Bhimashankar – 2 plots and Mahabaleshwar – 3 plots. These plots were established by British in 1930s and data collection of the trees with respect to the girth of the tagged trees was done till early 1990s from these plots. This system should be revived by adding the climate parameters for long monitoring and newer plot sites should be identified for the same purpose. During mid 1990's under externally aided forestry project (possibly World Bank Forestry project) forest monitoring plots were established with a specific design in many protected areas in Maharashtra such as Phansad WLS and also the baseline data was collected. If the process is continued then there is a need of analysing the information for enhancing the ecological understanding of the region and species. If these plots are not maintained at this point of time then there is a need to revive those. The forest monitoring plot will be a good indicator of measuring the carbon enhancement in the State, species turn over with the changes in climatic regimes. Specific efforts should also be made to monitor the micro-climate of various habitat types to understand the climate thresholds of the key species.

All the three priorities to tackle the impacts of climate change in Maharashtra could be achieved by developing Green Maharashtra Mission (GMM) as an immediate follow up of

National Action Plan on Climate Change (NAPCC). The details of are mentioned in the following section.

11.8.4 Fisheries

Maharashtra stands third amongst the Indian maritime states in terms of marine fish landings. Approximately 162 landing centers exist along the five coastal districts of the state, namely Greater Mumbai, Thane, Raigad, Ratnagiri and Sindhudhurg. Major fishery resources in the state include the Bombay duck, non-penaeid prawns[34]. Approximately 75 coastal fishing villages of Maharashtra are located within 100 m from the high tide line[35]. The fisher communities mainly belong to the *Bhois*, *Gabit*, *Kolis* and *Khirvis*, and the boat makers belong to the '*Tandel*' community. Most of the creek fisheries are exploited either using manual or small-mechanized vessels, but the financial status of the communities is so backward that often they do not actually own the boats.

A complete understanding of the past trends and the current scenario is required to understand the future of the Maharashtra's fisheries. While delineating the effects of climate change from existing human stressors is a difficult task, climate change will definitely exacerbate the impact of these stressors. Fishing is likely to make marine populations more sensitive to climate and make marine systems less resilient and more susceptible to the stresses caused by climate variability and change. While the current study proves inconclusive and severe data limitations exist, it is essential to err on the side of caution and reduce non-climatic stress on existing fisheries, to increase their ability to cope in the face of changing climate. Studies need to be established in a systematic and standardized manner for a better understanding of expected impacts and thereby to help manage the Maharashtra's marine fisheries and ensure that the climate change will not compound existing stress on the system.

Currently, only landing data is available which focuses on only the commercially viable species. Time series data and research establishing links between climatic and oceanographic variables and fish abundance is currently lacking. Reasonably long time series data between climatic and oceanographic parameters is required to detect displacement of stocks and changes in productivity.

Existing studies from CMFRI do not account for a number of non-climatic variables that might be responsible for changing distributions. Changing tastes and markets, price paid for various fish species, change in type of gear and effort, level of mechanization and the location of the actual catch, are factors that determine the composition of fish catch. These non-climatic factors often make it difficult to understand the impact of climate change, and therefore should be removed by de-trending analysis. In India, Maximum Sustainable Yield is calculated based on the landing data, which is heavily flawed, and therefore fishery potential estimates are not very reliable. A detailed understanding on the socio-economic conditions prevailing along the coastal districts is essential, to understand the vulnerability of the region to climate change.

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[34] Changing fish utilization and its impact on poverty in Maharashtra (2001). Draft A scoping study prepared under Project R7799: "Changing Fish utilization and Its Impact on Poverty in India." A Project Funded under DFID's Post-Harvest
Fisheries Research Programme

[35] Climate Change. DARE/ICAR Annual Report 2009-2010. http://www.icar.org.in/files/reports/icar-dare-annual-reports/2009-10/Climate-Change.pdf

Currently, nearly all the available data on how fishes respond to changes in these environmental factors comes from temperate species and these results might not be directly applicable to tropical marine fishes. Regional models are required to assess the implications of climate change on fish to understand dispersal patterns, to understand spatial and temporal patterns of various fish species, and there is a need to understand the ability of fish to cope with a changing climate (thresholds).

The INCCA Report brings to attention the fact that a lack of simulation models in the fisheries sector has made it impossible to evaluate the 2030 scenario on fisheries[36]. Current information on impacts of climate change on the sector comes from the analysis of past data and its interpretation in relation to changes in weather and sea-surface temperatures in those periods.

It is essential to employ the precautionary principle and manage the states fisheries with certain caution. Adaptation options should include the diversification of fishing grounds, diversification of fishing gear, diversification of livelihoods, reduce efforts and switch to an ecosystem based fisheries management.

11.8.5 Mangroves

Maharashtra has a long coastline of 720 Kms comprising of five districts viz; Thane, Raigad, Greater Mumbai, Ratnagiri and Sindhudurg. Thane has the largest share of mangrove area, which is also one of the case study areas of the project, and is followed by Raigad. There are excellent mangrove areas in Navi Mumbai along the coastline particularly near Palm Beach Road, Nerul, Koparkhairne[37], which face a severe threat of destruction/ degradation due to disposal of waste, and abuse of land for various unauthorized uses which are left unmonitored and unregulated. Further to this, there is an observed decline of the mangrove cover from 140 Sq. Kms in 1987 to 108 Sq Kms in 1990[38].

Protection, restoration and rehabilitation of mangroves is essential to ensure their continued survival. There is a need to set up a systematic method for collection of information, and to ensure the development of robust baselines to help predict future impacts with greater accuracy.

11.8.6 Corals

Corals in Maharashtra are found in Ratnagiri (patchy reefs), Malvan (nine species including a species of stony coral), and Colaba, Mumbai (large well-developed hard colonies). While the corals located in Malvan Marine Sanctuary are protected (under the Wildlife Protection Act, 1972), there is a need to design and maintain networks of protected areas to increase resilience of the entire coral system found along the State.

- A long term monitoring program that will help illustrate the impacts of climate change on corals needs to be established.

36 INCCA: Indian Network for Climate Change Assessment. Climate Change and India: A 4x4 Assessment. A Sectoral and Regional Analysis for 2030s. Ministry of Environment and Forests, Government of India, November 2010

37 http://envis.maharashtra.gov.in/envis_data/newsletter/july/bio3.html page last viewed on 21st of March 2013

38 State of the Forests report, 2001,Ch 5, pg 36
(http://envfor.nic.in/nfc/s-chap-5.pdf)

- While saltpans are absent, no coral mining observed and no erosion or accretion has been reported and aquaculture is not practiced within 10-km range in Malvan, this needs to be extended throughout the coast where corals are noticed. Also, local communities need to be involved to improve the recovery potential of damaged reefs by initiatives like reducing fishing pressure and addressing point sources of pollution.
- Restorative technologies that could reduce the impact of climate change on corals in tourist hot spots (e.g. Malvan) need to be explored.

11.9 Key recommendations

- Enhance quality of forest cover and improve ecosystem services
- Diversify livelihood options
- Promote scientific monitoring and research for improved decision-making

11.10 Action plan

11.10.1 Launch a Green Maharashtra Mission 2020 for biodiversity conservation

The National Mission for a Green India, as one of the eight Missions under the NAPCC, recognizes that climate change phenomena will seriously affect and alter the distribution, type and quality of natural biological resources of the country and the associated livelihoods of the people. Mission for a Green India (henceforth referred to as Mission) acknowledges the influences that the forestry sector has on environmental amelioration though climate mitigation, food security, water security, biodiversity conservation and livelihood security of forest dependent communities.
GIM puts “greening” in the context of climate change adaptation and mitigation. Greening is meant to enhance ecosystem services such as carbon sequestration and storage (in forests and other ecosystems), hydrological services and biodiversity; as well as other provisioning services such as fuel, fodder, small timber and non-timber forest products (NTFPs).

The Mission aims at responding to climate change by a combination of adaptation and mitigation measures, which would help:

- enhancing carbon sinks in sustainably managed forests and other ecosystems;
- adaptation of vulnerable species/ecosystems to the changing climate; and
- adaptation of forest-dependent communities

The following table summarises the proposed sub-missions and activities and the associated national targets.

Table 3 Sub-Missions and Activities of Green India Mission

Sub Mission 1: Enhancing quality of forest cover and improving ecosystem services (4.9 m ha)	
	Moderately dense forest cover, but showing degradation: 1.5 mha
	Eco-restoration of degraded open forests: 3 m ha
	Restoration of Grasslands: 0.4 m ha
Sub Mission 2: Ecosystem restoration and increase in forest cover (1.8 m ha)	
	Rehabilitation of Shifting Cultivation areas: 0.6 m ha
	Restoring Scrublands: 0.8 m ha
	Restoration of Mangroves: 0.10m ha
	Restoration of abandoned mining areas: . 0.1 mha
Sub Mission 3: Enhancing tree cover in Urban and Peri-Urban areas (including institutional lands): 0.20m ha	
Sub Mission 4: Agro-Forestry and Social Forestry (increasing biomass and creating carbon sink): 3 m ha	
Sub Mission 5: Restoration of Wetlands: 0.10m ha	
Cross-cutting Interventions:	
	Improving fuel-use efficiency and promoting alternative energy sources:
	Community Livelihood Enhancement
	Corridors for connectivity
	Community conserved areas and sacred groves
	Understanding, identifying and protecting areas/catchments of hydrological importance
Strengthening Institutions for Decentralized Forest Governance	
	Strengthening decentralized governance through Gram Sabha and its committees/ groups
	Revamping JFMCs
	Revamping FDA
	Building capacity of local institutions
	Building a cadre of Community Foresters
	Role of NGOs
	Strengthening the Forest Department

Maharashtra has an excellent opportunity to participate in GIM. On pilot basis three landscape / operational units could be identified from the regions such as Sahyadri (including slopes of Mawal and Konkan), Central Maharashtra (Grassland dominated areas) and Vidarbh (forested areas). There are two activities - Restoring/Planting Seabuckthorn and Ravine Reclamation which are not applicable to Maharashtra as per the GIM document.

What is the difference between GIM and proposed GMM?

The implementation of GIM is confined to an identified landscape of few thousand hectares and the priorities of the identified landscapes would suit local requirements and would thus contribute to the national targets as mentioned in table 4. In case of GMM, the implementation would be defined by the local priorities irrespective of the size of the landscape and the outcome would contribute to the national target to be achieved as defined by GIM. So GMM could become a component of GIM.

Following table 4 attempts to identify the activities which can be undertaken in various parts of Maharashtra within the framework of GIM as a part of Green Maharashtra Mission.

Table 4 Defining focus of Green Maharashtra Mission with respect to Green Indian Mission for implementation

Sub-missions and activities	Focus
Sub Mission 1: Enhancing quality of forest cover and improving ecosystem services	**Western Ghats and Vidarbh with focus on regeneration, habitat conservation and corridor development**
Activity 1 - Moderately dense forest cover, but showing degradation	Need to identify sites where possibility of reverting those sites back to the original habitat types
Activity 2 - Eco-restoration of degraded open forests	Focus on northern Western Ghats (north of Bhimashankar, Harishchandragad) for restoration and prevention of soil loss. Possible models for Payment for Environmental Services (PES)
	Forests in Yavatmal, Buldhana and Gondiya could be in focus for regeneration of NTFP species
Activity 3 - Restoration of Grasslands	Washim, Akola districts could be the focus for rediscovery of lesser Florican from the area
Sub Mission 2: Ecosystem restoration and increase in forest cover	**Use of Ecosystem approach for the restoration of over 21000 sq km Open forests in the state**
Activity 1 Rehabilitation of Shifting Cultivation areas	Developing livelihood alternative models in specific areas of Sahydri and Vidarbh
Activity 2 - Restoring Scrublands	About 3170 sq km of scrublands spread over 12 districts could the focus
Activity 3 - Restoration of Mangroves	Places where the developmental activities have been responsible to destroy the mangrove vegetation
Activity 4 - Restoration of abandoned mining areas	The stone mining in the Sahyadri and coal mining areas Vidarbh
Sub Mission 3: Enhancing tree cover in Urban and Peri-Urban areas	**Cities with high rate of development in the peri-urban areas like Pune could be focussed**

Sub Mission 4: Agro-Forestry and Social Forestry	**Limited efforts in the state. Models could be developed in Konkan - based on Mango and coconumt and Vidarbh - based on Bamboo**
Sub Mission 5: Restoration of Wetlands	**Tank based irrigation and fishery management system in many districts in Vidarbh could be the focus**
Cross-cutting interventions	
Activity 1 - Improving fuel-use efficiency and promoting alternative energy sources	Fuel efficient stoves and other cooking alternatives for fringes of Protected Areas
Activity 2 - Community Livelihood Enhancement	At the regions having NTFP based livelihood to increase income levels by value addition at the local
Activity 3 - Corridors for connectivity	Connecting remnant patches of forests in northern Sahyadri as well as create new corridors
Activity 4 - Community conserved areas and sacred groves	Building upon BNHS documentation of Sacred Groves in the State
Activity 5 - Understanding, identifying and protecting areas/catchments of hydrological importance	The catchment of one of the major dams like Jaikwadi could be treated under this activity.

Sub Mission 1: Enhancing quality of forest cover and improving ecosystem services

The enhancement of the forest cover along with the improvement in ecosystem services could be targeted at the forested regions of Sahyadri and Vidarbh. The forests in the southern Sahyadri are faced with the challenge of regeneration whereas the northern forest areas require development of corridors with plantation of suitable species for habitat conservation. In Sahyadri and Vidarbh there has been a substantial dependence on the ecosystem services from the forests such as water, non-timber forest produce (NTFPs), etc. Efforts can be oriented in these two regions under the Sub Mission 1 of M-GIM.

Activity 1 - Moderately dense forest cover, but showing degradation

The areas / habitats in the Sahyadri and Vidarbh can be identified where there is a possibility of reverting those sites back to the original forest types and strengthen the efforts of habitat conservation.

Activity 2 - Eco-restoration of degraded open forests

For this activity in the northern Sahyadri (north of Bhimashankar, Harishchandragad) could be specifically targeted considering the need of restoring the forests over there along with ensuring prevention of soil loss and degradation of exposed soil due to high rainfall. In Vidarbh region the forests on the western fringe from districts such as Yavatmal, Buldhana and the northern boundary like Gondiya could be the focus considering dependence of the local especially tribal communities on NTFPs.

Corporate social responsibility (CSR) activities and the Ecological Wing of the Army can be mobilized to rejuvenate barren hillsides and degraded forests using carefully selected diverse native varieties.

These areas could also be effectively developed as models of Payments for Environmental Services (PES). The local ecology provides an opportunity to develop the models such as eco-tourism which would help in restoring the ecology and in turn develop livelihood options for the local communities.

Activity 3 - Restoration of Grasslands

The districts of Vidarbh namely Washim, Akola could be the focus of this activity where there has been rediscovery of the species like Lesser Florican recently.

Sub Mission 2: Ecosystem restoration and increase in forest cover

There has been a large area about 21095 km^2 under the Open forest category as per the FSI 2011 data in Maharashtra. These forests are of different types e.g. moist deciduous, thorny forests in the Grassland savannahs and so on. This particular mission provides an opportunity to have ecosystem approach than only afforestation.

Activity 1 Rehabilitation of Shifting Cultivation areas

The shifting cultivation is in vogue in limited areas of Sahyadri and southern Vidarbh mainly. In Sahyadri there is a need to provide alternative to this practice.

Activity 2 - Restoring Scrublands

As per the FSI (2013) data following districts are having extensive scrublands which could be targeted with priority.

Table 5 Distribution of scrub forests in Maharashtra

District	Scrub (sq km)
Ahmadnagar	555
Pune	493
Satara	365
Bid	357
Nashik	319
Thane	222
Aurangabad	193
Buldana	163
Sangli	156
Nanded	128
Amravati	116
Dhule	103

Many scrub lands are the manifestation of degraded forests and hence, through Assisted Natural Regeneration and other silvicultural methods these areas can be reverted back to the forested ecosystem.

Activity 3 - Restoration of Mangroves

Maharashtra has 750 km of coast line and mangrove restoration efforts can be undertaken at places where the developmental activities have been responsible to destroy the mangrove vegetation.

Activity 4 - Restoration of abandoned mining areas

The stone mining in the Sahyadri and coal mining areas Vidarbh need to be immediately taken up for restoration.

Sub Mission 3: Enhancing tree cover in Urban and Peri-Urban areas

The urban areas such as Pune which have encircled the peri-urban areas and also have lost substantial green areas would be important under this Sub Mission to address. Similarly, the existing green areas could be strengthened.

Sub Mission 4: Agro-Forestry and Social Forestry

Maharashtra has limited growth in Agro-forestry and M-GIM could be a good opportunity to develop it especially in the Konkan region where the models with respect to mango, coconut orchards could be developed and implemented. Under the social forestry so far in most of the places exotic species such as *Euclyptus* has been used but plantation models of bamboo could be effectively implemented in Vidarbh region. The technology can also be shared with the local people on the lands where the Community Rights have been provided under the Forest Rights Act, 2006.

Sub Mission 5: Restoration of Wetlands

The tank based irrigation and fishery management system in many districts in Vidarbh has been an important source of livelihoods. With a breakdown of *Mal gujari* system these huge waterbodies have been neglected. These wetlands could be the focus under this Sub Mission of M-GIM.

Cross-cutting interventions

Activity 1 - Improving fuel-use efficiency and promoting alternative energy sources

The alternatives for firewood with the help of fuel efficient stoves and other cooking alternatives such as gobre gas, solar cookers could be made available to the fringe villages of the protected areas.

Activity 2 - Community Livelihood Enhancement

This activity can be targeted at the regions having NTFP based livelihood where the value addition at the local level can enhance the income levels. The targeted NTFPs could be *Mahuwa* flowers (storage of the dried flowers), *Dhawda* gum (packaging and marketing), Honey (non-violent technique of honey hunting and marketing), bamboo (craft making and marketing), *Charoli* (packaging and marketing).

Activity 3 - Corridors for connectivity

The activity would involve two types where firstly, there could be development of corridors in the region of northern Sahyadri where the remnant patches of the evergreen forest can be effectively linked and secondly, the new corridors could be identified especially for the endangered species like Lesser Florican outside the protected area boundaries.

Activity 4 - Community conserved areas and sacred groves

BNHS has documented the Sacred Groves of Maharashtra which could be considered as the starting point for identifying and recognizing the sacred groves in the state for biodiversity conservation. These areas can be geo-referenced and can be officially recognized as Community Conservation Areas. Similarly, there have been several villages protecting the forests though the community efforts which could be potentially considered as Community Conservation Areas.

Activity 5 - Understanding, identifying and protecting areas/catchments of hydrological importance

The catchments and the backwater areas of the small and big dams in the state should be focus of this activity. Except few dams such as Koyna the catchment areas have been poorly protected. The catchment of one of the major dams like Jaikwadi could be treated under this activity.

Strengthening Institutions for Decentralized Forest Governance

The Green India Mission is oriented at the reforming the forest governance by integrating with the PRI system. In this regard, Maharashtra State has linked the Joint Forest Management Committees with Gramsabha. This has been an important step in decentralising the forest management in the State. But it is necessary to exercise the implementation of these provisions in the spirit of the GR. In comparison to States like Odisha, Chhattisgarh, in spite of having excellent potential of NTFPs JFM activities in Maharashtra have not been evolved. GMM could be another attempt to actually have a revamped and decentralised forest management in targeted areas of Vidarbh especially Gadchiroli district where under Forest Rights Act extensive areas have been declared as Community Forest Rights. Also the region already has a provision of *Nistar* land to be managed by the local communities for the subsistence purposes. The activities listed under this category namely Strengthening decentralized governance through Gram Sabha and its committees/ groups, Revamping JFMCs, FDAs, Building capacity of local institutions, Building a cadre of Community Foresters, defining role of NGOs and also strengthening the forest department could be implemented on pilot scale in target areas of Vidarbh.

Financial Mechanism for Green Maharashtra Mission

GIM is supposed to be costing about Rs 46000 crores over a decade at national level covering about 10 million hectares for treatment. MoEF will be providing Rs 1000 crores annually under new budget head of GIM, under discussion with Planning Commission. At national level there is a convergence of funding scheme anticipated as follows –

a) MG NREGS – 2.5% i.e. 1500 crores

b) CAMPA – 800 crores

c) National Afforestation Programme – 80 crores
d) Integrated Forest Management Scheme – 20 crores
e) Ministry of New and Renewable Energy Resources – 200 crores
f) XIII th Finance Commission Grant – 200 crores
g) Integrated Watershed Management Programme – 200 crores
h) National Clean Energy Fund – 500 crores

This fund allocation constitutes about Rs 4500 crores annually. The gap of about Rs 1000 crores is expected to be bridged by external support.

The State has been already implementing the programmes under these specified schemes for convergence at the national level. There is need to evolve similar convergence of these schemes according to the local focus of various districts as identified in table 5 to implement the respective activities. Along with the convergence fund the state will also be in a position to effectively use the funds from various other centrally sponsored schemes for protected areas, etc. The state will also be able to revive many programmes which were launched through externally aided projects such as establishing monitoring plots in many protected areas.

11.10.2 Adaptation Action: Development of Buffers

Action category: Action oriented research and implementation in villages surrounding biodiversity rich areas such as protected areas with an approach of short term research inputs for long term action plans. The activities are mainly oriented at rural population and specific groups.

Rationale: The pressure on biodiversity rich areas in form of fuel wood, fodder has been responsible for degradation of forests. This is resulting into reduced capacity of the forests to sequester carbon, reduced extent of ecosystem services being available from ecosystems and increased vulnerability of ecosystems to impacts of climate change due to the resulting degradation of natural resources. The areas surrounding the network of protected areas in the state and the identified about 33 priority conservation areas need interventions in terms of reducing the pressure for fuel wood and grazing for maintaining the habitats for biodiversity conservation and carbon sequestration. The integrated approach of combining modern technology and conventional silvicultural methods would form an effective strategy for implementation.

Key components of the action:

1) Assessment of fuel wood, grazing requirements and other forest dependence and sustainable harvesting limits to the extent possible in villages surrounding biodiversity rich areas including protected areas
2) Designing the technological and natural resource management interventions for implementation
3) Development of Sustainable Harvesting Practices for the non-timber forest produce

4) Development of alternative livelihood opportunities to reduce pressure on the forests
5) Developing indicators of ecosystem restoration as an impact of the diversion of anthropogenic pressures

Expected outcomes:

1) Extent of area developed as fuel wood plantation
2) Extent of area developed as fodder resource
3) Percentage of demand of fuel wood met through integrated measures
4) Number of households supplied with alternative technologies for cooking energy
5) Number of options developed for alternative livelihood
6) Training module developed for Sustainable Harvesting of the selected species
7) Extent of area restored back to near natural conditions

Implementation:

- Timeframe: Five to ten years
- Links with ongoing govt. initiatives: The government initiatives converged for GIM are applicable e.g. National Afforestation Programme, National Clean Energy Fund, etc.
- Nodal Govt. Department and cross-department association (if any): State Forest Department as nodal agency and site specific cross-departmental association to be explored
- Specific capacity needs: 1) Capacity building of the local communities for maintenance of the cooking energy technologies 2) Develop the monitoring mechanism for assessing the impact on the ecosystems 3) Financial sustainability of livelihood options for post intervention period
- Cost estimate and source of finance: Green India Mission

Choice criteria:

- Relevance: The buffer development would not only reduce the anthropogenic dependence on the ecosystems but would also explore alternative livelihood options. The technological inputs such as alternative fuel, sustainable harvesting techniques would allow optimal utilization of the natural resources.
- Consistency: The identified priorities are in congruence with Green India Mission of Central Government and other species specific conservation schemes.
- Feasibility: The financial mechanism of Green India Mission provides an opportunity to use the convergence approach of several centrally sponsored schemes to take appropriate actions on the ground level. The external aids from corporates, bilateral / multilateral donors could also be explored by developing specific proposals.
- Capability: The State Forest Department in collaboration with local and national (also international wherever necessary) institutions and local communities can execute.

11.10.3 Adaptation Action: Biodiversity conservation

Action category: Action oriented research and implementation in identified three regions (Sahyadri ranges – northern and southern, priority conservation areas and grassland dominated areas) with an approach of short term research inputs for long term action plans. The activities are mainly oriented at rural population and specific groups such as hunting nomads.

Rationale: The biodiversity rich areas in northern Sahyadri ranges are facing the risk of fragmentation whereas the southern ranges regeneration of the important species is in danger. The grasslands in the central region are showing anecdotal evidences of re-discoveries of near extinct species with a participatory approach of working with local communities. The identified about 33 priority conservation areas need interventions in terms of maintaining the habitats for conservation. Hence, there is a need to go beyond the conventional approaches of biodiversity conservation to sustain and enhance the range of ecosystem services and carbon sequestration capacities without compromising upon the biodiversity richness. To achieve these objectives GIM is a recognized source of finance through convergence of several centrally sponsored schemes available immediately.

Key components of the action:

6) Identification and developments of and corridors in northern Sahyadri
7) Assisted Natural Regeneration for southern Sahyadri
8) Identification of habitat for grassland animals and birds beyond the protected area boundaries and develop participatory conservation strategy

Expected outcomes:

1) Development of corridors for northern Sahyadri – Number of patches identified and extent of area developed as corridor
2) ANR in southern Sahyadri – Introduction of identified number of species in respective habitats and monitoring process established to confirm survival
3) Conservation of grassland fauna – Number of suitable habitats identified and conservation action plans developed for the sites

Implementation:

- Timeframe: Five years
- Links with ongoing govt. initiatives: Annual Recovery Plans for the Great Indian Bustard, Lesser Florican by the centrally sponsored scheme of MoEF Integrated Development of Wildlife Habitats (CSS-IDWH)
- Nodal Govt. Department and cross-department association (if any): State Forest Department as nodal agency and site specific cross-departmental association to be explored; Ecological wing of Army can be mobilized
- Specific capacity needs: 1) Understanding ecological succession of the forest patches for introduction of specific plant species 2) Developing conservation action plans on sites not owned by the State Forest Department
- Cost estimate and source of finance: Green India Mission, Corporate Social Responsibility funds

Choice criteria:

- Relevance: The corridor development and species re-introduction would possibly prevent natural biodiversity rich habitats from shrinking in size and possibly build resilience for their long term survival.
- Consistency: The identified priorities are in congruence with Green India Mission of Central Government and other species specific conservation schemes.
- Feasibility: The financial mechanism of Green India Mission provides an opportunity to use the convergence approach of several centrally sponsored schemes to take appropriate actions on the ground level. The external aids from corporates, bilateral / multilateral donors could also be explored by developing specific proposals.
- Capability: The State Forest Department in collaboration with local and national (also international wherever necessary) institutions and local communities can execute.

11.10.4 Adaptation Action: Ecosystem research on climate variability

Action category: Development and enhancement of research design oriented at important habitats, species so as to develop the measures to tackle the climate variability for sustained carbon enhancement and biodiversity conservation.

Rationale: The climate projections done by INCAA, IBIS model and TERI suggest that there would be substantial changes in extent and number of days of precipitation, frequency of heat waves, etc. for different eco-regions in Maharashtra. These climatic changes would be major drivers for changes in species composition and hence also responsible for changes alterations in the ecosystem services and biodiversity conservation. GIM also emphasizes the Research and Development with respect to the objectives of the mission such as long-term research to study vegetation response to climate change.

Key components of the action:

9) Revival of forest monitoring plots at places such as Bhimashankar, Mahabaleshwar, several protected areas, etc.
10) Development and establishment of monitoring mechanisms for other ecosystems, habitats, species, etc.

Expected outcomes:

4) Develop State-specific carbon enhancement estimates with a monitoring mechanism
5) Develop real time information about the impacts of local climate variability in the context of larger process of climate change
6) Develop adaptation interventions for biodiversity conservation and continued flow of ecosystem services based on the real time information

Implementation:

- Timeframe: Fiver years
- Links with ongoing govt. initiatives: Ongoing schemes of the MoEF such as All India co-ordinated project of Biodiversity, Taxonomy, etc.,
- Nodal Govt. Department and cross-department association (if any): State Forest Department as nodal agency and site specific cross-departmental association to be explored
- Specific capacity needs: 1) Capacity building for understanding objectives and processes of monitoring mechanism 2) participation of the local communities in research activities
- Cost estimate and source of finance: Green India Mission

Choice criteria:

- Relevance: Availability of real time information for building resilience
- Consistency: The identified priorities are in congruence with Green India Mission of Central Government and other species specific conservation schemes.
- Feasibility: The financial mechanism of Green India Mission provides an opportunity to use the convergence approach of several centrally sponsored schemes to take appropriate actions on the ground level. The external aids from

corporates, bilateral / multilateral donors could also be explored by developing specific proposals.

- Capability: The State Forest Department in collaboration with local and national (also international wherever necessary) institutions and local communities can execute.

11.10.5 Adaptation Action: Reducing the non-climatic stressors on the mangrove ecosystem by formulation of Regional Monitoring Networks

Action category: Long-term institutional capacity building; awareness generation; strategic knowledge generation

Rationale: While having consultations with the district officials in Maharashtra, especially the Mangrove cell, it was observed that there is an urgent need to identify key areas of concern for mangroves and undertake action oriented initiatives in collaboration with the key stake holder of the state. Though the mangroves of Maharashtra are now well protected under the Coastal Regulation Zone law, there still emerges a profound need establish a robust and effective monitoring network. Thus **Regional Monitoring Networks** (RMNs) are proposed to be established to further monitor the implementation and effectiveness of the Policies and acts pertaining to the conservation of the coast.

Key components of the action:

4. Formulation of a regulatory body comprising of a members from relevant authorities like Forest department, Mangrove cell, Ministry of Environment and Forest (MoEF) to undertake decisions and actions pertaining to monitor the security of these ecosystems.
5. Allocation of following responsibilities to the committee:
    a. Monitoring and penalization towards the disposal of solid waste, effluents, industrial waste, debris and other dumping.
    b. Allocating key responsibilities to the regional networks to impose penalties against the non-compliance of the state level policies and acts.
    c. Encouraging the local community participation towards the maintenance of these ecosystems through various already existing state level programs like Joint Forest Management etc.
6. One of the key tasks of these regional networks also would be to building capacities of the communities as well as the district officials including the key decision makers about the significance of these ecosystems and the subsequent linkages with climate change.

Expected outcomes:

1. Enhanced resilience of these ecosystems towards the increasing impacts of future climate change.

2. Reduced discharge of the harmful effluents would improve bio diversity of the region, which is otherwise affected owing to unmonitored discharges.
3. Involvement of the local communities towards Management of the ecosystems.

Implementation:

Timeframe	**Short term:** Formulation of the **Regional Monitoring Networks** (RMNs) in Thane (one of the case study districts) in a year's time. Identifying and allocating the appropriate roles and responsibilities to these networks. Carrying out detailed gap analysis of these networks and undertaking desired improvements for the implementation in the next set of regional networks. Conducting a district level workshop for the of the Thane district officials to identify the gaps in the programs like ICZM, JFM, Environment Protection Act, CRZ notification, etc. and its implementation process.
	Long term: Formulation of the RMNs (only after the assessment of the functioning of the already existing ones) in other 4 coastal districts of the state in next 5 years.
Links with the ongoing activities	**The Territorial Waters, Continental Shelf, Exclusive Economic Zone and Other Maritime Zones Act (1976)**[39] provides for "certain matters relating to the territorial waters, continental shelf, shelf, exclusive economic zone and other maritime zones of India." According to the provisions of this act the Central Government of India, has in the continental shelf, sovereign rights for the exploration, exploitation, conservation and management of all resources (Section 6(3a)) and also has exclusive jurisdiction to preserve and protect the marine environment and to prevent and control marine pollution **CRZ notification 2011,** restricting the construction activities in the coastal zone, protecting the ecologically sensitive and the geomorphological features which play a role in the maintaining the integrity of the coast.
Nodal Government Department	For Lakes: Environment Department, GoM. Mangrove Cell, GoM. Maharashtra Coastal Zone Management Authority, MoEF, GoI Overlooking agencies: Forest Department

Choice criteria: Mangrove forests face threats caused by anthropogenic activities such as pollution, habitat conversion and degradation, Kharland bunding, aquaculture and grazing.

[39] The Territorial Waters, Continental Shelf, Exclusive Economic Zone and Other Maritime Zones Act (1976). Online at http://meaindia.nic.in/actsadm/30aa13.pdf

Approximately 40% of the mangrove cover lost over the last two and a half decades is because of anthropogenic interference and clearance by the State Kharland Development Board, with habitat conversion and wood felling perceived as major threats observed for Maharashtra's mangrove [40]. The coastal areas are also severely subjected to the developmental projects like damming the rivers of the Western Ghats for water storage and power generation. As per our study, the temperatures and rainfall for the coastal/western Maharashtra is projected to increase in the coming decade. Thus, these impacts are only expected to get compounded further exacerbating the threat to these sensitive ecosystems. In the absence of regular monitoring and safeguarding networks, these threats would endanger the existing species, further exposing the coast to the future impacts of climate change.

[40] Dr. Mahesh Shindikar. Coastal Areas – Problems and Conservation (in Maharashtra with special reference to Mangroves). Online at http://envis.maharashtra.gov.in/envis_data/pdf/Comptn09/Art_MRShindikar_1st.pdf

Appendix 1 - Prioritization of sites for biodiversity conservation in Maharashtra

Sr no	Location	Category - WS/NP / IBA / Hotspot, etc.	Description	Source
1	Ambavane-Khandala valley	Hotspot	One of the northernmost refuge for preclimax and disturbed climax vegetation. Its an important corridor between Bhimashankar WS and Mahabaleshwar (south) and Phansad WS (west)	Ranwa 1993
2	Amboli-Sawantwadi	Hotspot, CEPF priority area	The area covering mean sea level to Western Ghats mountain top dominated by evergreen vegetation. In the context of the Western Ghats the region is the northern limit of the most typical of southern Western Ghats vegetation.	Ranwa 1993, CEPF 2006 and ATREE
3	Sanjay Gandhi National Park - Tungareshwar Complex (additional area for IBA)	Hotspot, NP, IBA	The area harbours important fauna along with deciduous vegetation which is generally poor in endemic and endangered species. The IBA includes a complex consisting of Sanjay Gandhi National Park (10,307 ha), Tungareshwar Wildlife Sanctuary (8,570 ha) and Reserve Forests between them. Nearly 300 bird species have been identified from the IBA. The site lies in the Western Ghats Endemic Bird Area (EBA 123).	Ranwa 1993, BNHS 2004
4	Bhimashankar Wildlife Sanctuary	Hotspot, WS, IBA	The WS harbours northernmost climax evergreen forest vegetation and fauna such as Bhimashankari Giant Squirrel. But it is poor in terms of endemic species. It is also one of the IBAs with more than 172 recorded bird species. Many bird species having their northern ranges in this area.	Ranwa 1993, BNHS 2004
5	Chandoli Wildlife Sanctuary	Hotspot, WS	The WS serves as a corridor between Koyana WS and Radhanagari WS with dominance of secondary evergreen forests.	Ranwa 1993
6	Karnala Bird Sanctuary	Hotspot, WS	Small pocket of semi-evergreen vegetation with excellent bird population but relatively insignificant in comparison to northern pockets such as Boriwali NP.	Ranwa 1993
7	Kalasubai-Harishchandragad Wildlife Sanctuary	Hotspot, WS	The region is important for sheltering the northernmost flora and fauna of evergreen forests of the Western Ghats. The area is dominated by fragmented evergreen, semi-evergreen and deciduous forests	Ranwa 1993

Sr no	Location	Category - WS/NP / IBA / Hotspot, etc.	Description	Source
8	Koyna Wildlife Sanctuary	Hotspot, WS, IBA	The WS harbours the only available climax evergreen forest vegetation of higher altitude in the state having high levels of endemism. It is also marked by unique fauna. This IBA site is one of the undisturbed forests of the Western Ghats Endemic Bird Area. Two restricted range species have been seen, but more research is needed.	Ranwa 1993, BNHS 2004
9	Mahabaleshwar plateau and Hill Complex	Hotspot, CEPF priority area	Tropical montane climate supported vegetation with unique flora and fauna.	Ranwa 1993, CEPF 2006 and ATREE
11	Marleshwar	Hotspot	The temple grove is one of the last patches of the climax semi-evergreen vegetation of Konkan harbouring Great Pied Hornbills	Ranwa 1993
12	Matheran	Hotspot	The vegetation on the plateau and slopes form an outlier of Western Ghats mountain range with secondary climax formation and harbouring endangered fauna.	Ranwa 1993
13	Phansad Wildlife Sanctuary	Hotspot, WS	The WS supports the climax evergreen vegetation at the low elevation which is otherwise found only in Amboli region far southwards.	Ranwa 1993
14	Radhanagari Wildlife Sanctuary	Hotspot, WS, IBA	Apart from the higher endemic vegetation dominated by evergreen and semi-evergreen species, the area is in continuation of the southern Western Ghats. The site lies in the Western Ghats Endemic Bird Area (EBA 123) where 16 restricted range have been identified species. Two have been identified from this site but more are likely to occur here.	Ranwa 1993, BNHS 2004
15	Burnt Island Vengural Rocks	IBA	The archipelago comprises about 20 islets in an area about 5 km from north to south and 1.6 km from east to west in Sindhudurg district. It is a nesting site for marine birds, terns, pigeons and swiftlets.	BNHS 2004
16	Gangapur Dam and Grasslands	IBA	Dam in Nasik district surrounded by grasslands. It harbours rare grassland birds such as Lesser Florican and shelters the conglomeration of aquatic birds in winter.	BNHS 2004
17	INS-Shivaji and Lonavala	IBA	The presence of this defence establishment, spread over 1,500 acres, has served to protect some valuable original tropical moist/semi-evergreen forest and land grassland habitats.	BNHS 2004
18	Jaikwadi Wildlife Sanctuary	WS, IBA	The site is an important stopover in the migratory flyway of cranes and other birds, which congregate here during their return migration	BNHS 2004

Sr no	Location	Category - WS/NP / IBA / Hotspot, etc.	Description	Source
19	Jawaharlal Nehru Bustard Sanctuary	WS, IBA	Within the Sanctuary, the grassland plots where the Great Indian Bustard is regularly seen are identified as IBAs	BNHS 2004
20	Mahul-Sewree Creek	IBA	Despite the high degree of pollution, the area is a winter refuge for thousands of migratory birds from as far as the Arctic circle. They include sandpipers, plovers, gulls and terns. The area also supports a large congregation of flamingos, which are local migrants probably from Gujarat.	BNHS 2004
21	Melghat Tiger Reserve	NP, IBA	Melghat is one of the best areas to see species of the Indo-Malayan Tropical Dry Zone (Biome-11). Out of the 59 species identified by BirdLife International (undated), 44 have been seen here till now. Melghat Tiger Reserves is one of the few sites in India that come under the Secondary Area category of BirdLife International.	BNHS 2004
22	Nagzira Wildlife Sanctuary	WS, IBA	Nagzira has been selected as an IBA primarily for its biome species. It is one of the best areas to see the species of Indo-Malayan Tropical Dry Zone (Biome-11). Of the 59 species identified by BirdLife International (undated), 28 have been seen here.	BNHS 2004
23	Nandur Madhameshwar Wildlife Sanctuary	WS, IBA	At least 253 species of birds are known to occur in the region, the majority of which are migratory. The reservoir is an important staging and wintering ground for migratory waterfowl. This wetland is a prime candidate as a Ramsar site.	BNHS 2004
24	Nawegaon National Park	NP, IBA	The site is an excellent combination of aquatic bird species and birds of tropical dry deciduous forests. The area is notable for southern limit of Sarus cranes and existence of Red and Grey Jungle fowls.	BNHS 2004
25	Ozar and Adjoining Grassland	IBA	The grassland is rich in avifauna with more than 200 species identified till now, most notable are Lesser Florican and Great Indian Bustard	BNHS 2004
26	Tadoba National Park and Andhari Tiger Reserve	NP, IBA	This site harbours the typical birds of Tropical Dry Deciduous Forest of central India. Of the 59 species listed by BirdLife International (undated) for Biome-11, 23 have been seen here.	BNHS 2004
27	Taloda Reserve Forest	IBA	Taloda forest range is one of the refuges of the highly endangered and endemic Forest Owlet. Taloda is one of the few sites in India that come under the Secondary Area category of BirdLife International.	BNHS 2004

Sr no	Location	Category - WS/NP / IBA / Hotspot, etc.	Description	Source
28	Tansa Wildlife Sanctuary	WS, IBA	About 212 bird species have been recorded from Tansa. Besides the two Critically Endangered Gyps species of vultures, the Vulnerable Pallas's Fish-Eagle.	BNHS 2004
29	Thane Creek	IBA	Thane creek is one of the largest creeks in Asia and is located partly on the coast of Mumbai metropolis. Over 205 species of birds have been reported from this area. Thane Creek is a very important wintering ground for waterbirds.	BNHS 2004
30	Toranmal Reserve Forest	IBA	Toranmal Reserve Forest is considered to be one of the last refuges of the Critically Endangered, endemic Forest Owlet. It is one of the few sites in India that come under Secondary Area category of BirdLife International.	BNHS 2004
31	48 I/1/SE - Reserve Forests in Dodamarg	CEPF priority area	Degraded semi-evergreen forests in Kalasgade RF and Parle RF, Changadh range and NE of Dodamarg for *Cinnamomum goaense, Nothopegia castanaefolia*	ATREE, CEPF 2006
32	47 F/8/NE - Sinhagad Reserve Forest	CEPF priority area	Sinhagad Reserve Forest for Millardia kondana	ATREE, CEPF 2006
33	Bhimgad Reserve Forest	CEPF priority area	Reserve forests of high conservation value with near irreplaceable status	ATREE, CEPF 2006

12. Impacts of climate change on livelihoods in Maharashtra

12.1 Introduction

Climate change can act as an additional stressor for households and communities dependent for a major part of their livelihood on natural resources, whose distribution and productivity are influenced by climate dynamics. Livelihoods comprise capabilities, and materials and social assets necessary for means of living (Chambers and Conway 1992). Climate change can impact livelihoods through multiple pathways, and manifest risk in four different ways: across space, over time, across assets, and across households (Agrawal and Perrin 2009). Among the most vulnerable are communities like tribals and indigenous people, small holder famers, the landless, and women as their livelihoods are intrinsically dependent on natural resources, and any stress on these would have a direct or indirect impact on them. A wide range of diverse tools and methods have been used for understanding the vulnerability of livelihoods systems and strategies. In this regard Sustainable Livelihoods Framework is the most widely adopted approach. It integrates the vulnerability context along with livelihood assets, their interaction with policies and institutions and its consequent linkages with livelihood outcomes. The vulnerability context refers to shocks, trends and seasonalties while livelihoods assets refer to five different types: human capital, physical capital, and social capital, financial and natural capital. These five types of capital/assets give a household a livelihood platform, and access to this is either enhanced or thwarted by social relations such as gender and caste, or by institutions such as customs, land tenure or market practices. A household adopts different livelihood strategies in the context of demographic trends, technical changes and policies and programs, as well specific shocks like a drought, an epidemic or civil unrest. These comprise a set of natural resource-based activities such as farming, livestock rearing or fishing, as well as other activities like trading. Coping strategies adopted in times of crisis include sale of assets, livelihood diversification and migration.

Each section in this chapter is divided into two parts, first part is a synthesis of impacts from climate change variability on different types of livelihoods like agriculture based livelihoods, forest based and fisheries based livelihoods. The second part discusses the outputs from the household survey (HHS) which has been conducted in all six case study districts[41]. Understanding the perceptions of local population can give important insights for designing adaptation interventions which are both inclusive and could have a high probability of being adopted by the locals. A household survey can therefore provide that crucial insight into perceptions of people regarding climate change and its impacts on their livelihoods. A total of 1538 households were surveyed which included Hingoli (261); Nandurbar (259); Solapur (255);

[41] For the household survey one or two panchayats were then randomly selected and 125 households were covered in each block. The households were selected by systematic sampling.

Buldhana (252); Gondia (258); Thane(253, which includes 82 fisherman). The HHS aimed at understanding the local perceptions related to changes in climate, sensitivity of crops to climate, weather related outbreak of diseases, while also looking at accessibility of households to weather forecasting and other climate services, their dependence on fuel wood, observed changes in the occurrence of pest infestations, observed impacts etc.

The following villages were surveyed in each district.

Table 1: Districts, blocks and villages surveyed under household survey

District	Block	Villages	Sample size
Hingoli	Sengaon, Kalamnuri	Kosla, Pankan Gaon, Hatmali, Shivani, Umra	261
Nandurbar	Akkalkuva, Shahada	Babalpur, Suwadi, Brahmnpuri, Roshamal	259
Solapur	Akkalkot, Pandharpur, Sangola	Chapalgaon, Korthi, Akola	255
Buldhana	Khangaon, Lionar	Shirargaon, Weri, Gonapus, Kunt puri	252
Gondia	Davari, Amgaon	Mulla (Ghasuli tola),Thand, Dogergaon, Bhothali	258
Thane	Palghar, Wada	Dhansar, Sapen(khurd), Warle, Satpati, Posheri	253 (82-fishermen)

12.2 Impact of climate variability and change on agriculture based livelihoods in Maharashtra

Agriculture sector is one of the most vulnerable to climate change. Climate change will primarily affect the natural and physical asset base, making farming more difficult and unpredictable (World Bank, 2010). The IPCC (Parry et al, 2007) predicts with high degree of confidence an increase in the magnitude and frequency of extreme events including droughts, floods and cyclones. This can have an adverse impact on physical infrastructure required for agriculture, in terms of degraded farm land, sand casting of cultivable land, decline in soil productivity, damage to farm property, reduced irrigation facilities etc. Other effects will be seen as changes in crop seasonality and productivity caused by higher temperatures and precipitation. Increase in temperatures can reduce crop yield while encouraging weed and pest proliferation. Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Although increased temperatures will increase productivity of some crops in certain regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening food security (IFPRI, 2009 and Parry et al, 2007). These changes will directly impact the livelihoods of people primarily dependent on agriculture. However, vulnerability of populations to climate change is multi-dimensional and it does not manifest due to climate alone but rather arises in the presence of multiple stressors. Researchers acknowledge that it is not only the geographic location of the population, and the frequency and magnitude of the hazards, but also the social and economic condition of those at risk that combine to determine how people cope with and recover from changes in the environment (Adger, 2006; Cannon, 1994; Fussel, 2007; Wisner et al.2004).

Acharya (2006) notes that there are four principal ways of acquiring livelihoods by the rural households in India, wherein in largely referring to agriculture based livelihoods:

a) **Production-based livelihood**. A large proportion of the small and marginal farmers gain livelihoods through production on small pieces of land. For these households, availability or access to inputs and improved methods of production are quite critical for their livelihoods.
b) **Labor-based livelihood**. Most of the small landholders and landless rural households derive livelihoods by selling their labour. For their livelihoods, demand for labour, wage rates and prices of food are the critical factors.
c) **Exchange- or market based livelihood**. Those rural households which produce surplus food and non-food agricultural products or non-farm goods earn their livelihoods by selling these surpluses in the market. The marketing system for these products and relative prices of what they sell and what they buy, affect their livelihoods.
d) **Transfer-based entitlements**. The households without any income-earning asset or able-bodied person to work depend for their livelihoods on transfers from the government or other social organizations. Government's social security and food assistance programs

12.2.1 Review of agriculture based livelihoods in Maharashtra

Agriculture and allied activities contribute nearly 12% per cent to the Maharashtra State's income, although 55% of the population is dependent on them. Agriculture in Maharashtra is diversifying into high value crops of which horticultural crops are a major component. The state has 15 lakh hectares under different fruit crops. The state has a 14.5 percent share in the country's fruit production and ranks first amongst all the states; and contributes 27 per cent in area and 21.5 per cent in production (Planning Commission, 2007). Fruit-production during 2008-09 constituted 30.27 percent of the total agricultural produce (food grain and horticultural produce) in the State. The percentage of fruits in the total horticultural production of Maharashtra during 2009-10 was 61 percent (FICCI, 2011). Specifically, Maharashtra is the largest producer of seedless grapes (78%), banana (75%), mandarin oranges (75%), onion (63%), tomatoes (42%) of the total production in India. Alphonso mangoes accounts for 90% of India's export in mangoes. Further, the State is becoming one of the leading wine producing areas in the country. At present, out of 62 wineries in the country, 58 wineries are functioning in the State with an investment of Rs. 329 crore. The wine production in India is 2.25 crore litre of which 2.11 crore litre (97 per cent) is produced in Maharashtra. Any changes in temperature and precipitation can have significant impacts of these horticulture crops which are highly sensitive to climatic conditions. For example: Changing weather patterns are affecting the cultivation cycles of Maharashtra's 444,790 acres of grapes along with oranges. Maharashtra State Grape Growers Association had reported that rainfall in November for the last three to four years has delayed pruning and thus harvesting, making it increasingly difficult to meet deadlines for supplies of grapes sent to the European Union. Similarly Alphonso mango has been adversely affected. Experts say that the reason for the decline in output is because areas in the Konkan region where the Alphonso is grown have been hit by harsh winters. Fruit research experts say that fertilization process has been affected due to the decrease in winter temperatures of the coastal districts. All these put the livelihoods dependent on them at a grave risk as horticulture crops are often high input crops, which are highly climate sensitive , so any decline in yields due to changes in the climate can endanger the welfare of the these communities.

Table 2: Percentage distribution of workers as per 1991 and 2001 census

Class of workers	Rural		Urban		Total	
	1991	2001	1991	2001	1991	2001
Cultivators	46.7	42.4	3.2	1.8	34	28.7
Agricultural laborers	37.4	37.8	5.5	3.6	28.1	26.3
Household industry	1.5	2.3	2.1	3.4	1.7	2.6
Other classes	14.4	17.5	89.2	91.2	36.2	42.4
Total workers	24033	27261	9877	13912	33910	41173

Source: Census of India, 2001

The contribution of agriculture to states economy has declined over time and this is because of two reasons: a) unfavourable agro-climatic situation; and b) faster growth in other sectors, especially the service sector. The following, existing vulnerabilities in the state are likely to amplify due to impacts of climate change and can adversely impact the livelihoods of the people dependent on agriculture.

- The state of Maharashtra faces many pressures that directly impact the agriculture sector like; high population growth rate, increased use of fertilizers due to increased production demand, increased pressure on canals, wells and tube wells for irrigation etc. Skewed distribution of rainfall in the state, pose drought as a recurrent phenomenon in certain regions. More than 30% of the state falls under the rain shadow area where scanty and erratic rains occur and about 84% of the total area under agriculture in the state is directly dependent on the monsoon rainfall. While annual rainfall in the coast is found to vary between 1600-4800 mm, in the interiors/central belt, it is less than 600 mm. This comprises the drought-prone regions of the state. The proportion of irrigated area in the State is only around 16%, as opposed to the national average of 38%. The drought prone areas in the State are affected by low and inadequate rainfall, long dry spells and erratic distribution of rainfall. A very limited part of this area gets the benefit of major irrigation projects and the area under cultivation is very high in drought prone areas.

- Of the 100 talukas in the state, 45 have been identified as being drought prone, according to the Central Water Commission statistics (CWC, 2005). Due to regular drought frequency, low levels of irrigation coverage, literacy, and infrastructure development and poor coping & adaptive capacity, this region is highly vulnerable; to impacts of climate change. Uneven distribution of rainfall in the state & high rainfall variability has contributed to huge economic losses in the state.

- The frequency of droughts is projected to increase in future through changes in the hydrological cycle viz. precipitation, evapo-transpiration (ET), soil moisture etc. ET being the major component of hydrological cycle will affect crop water requirement, future planning & management of water resources.

- A study on sensitivity of ET to global warming for arid regions, has projected an increase of 14.8% in total ET demand with increase in temperature. It is also concluded that marginal increase in ET demand due to global warming would have a larger impact on the resource-poor, fragile arid zone ecosystem that constitutes a bulk of Maharashtra.

- Rice and sugarcane, two of the principle crops of the state are highly water intensive and climate sensitive. Changes in water availability along with increase in temperature could have profound effect on the productivity of these two crops. A World Bank Study (2008) estimated that the productivity of sugarcane could go down by 30%.

- Maharashtra has a prominent position on the horticultural map of India with more than 15 lakh hectares are under different fruit crops. The state has a 14.5 percent share in the country's fruit production and ranks first amongst all the states; and contributes 27 per cent in area and 21.5 per cent in production (Planning Commission, 2007). Any changes in temperature and precipitation can adversely impact the fruit production in the state, thereby endangering the livelihoods of those dependent on horticulture activities. It is estimated that as much as 30 - 35 % of fruit and vegetable production is lost on account of lack of adequate post harvest infrastructure in the state. Agricultural produce of the farmers do not get remunerative prices due to lack of grading, proper packaging and in turn there is huge post harvest losses.

- Though there is a good amount of marketable surplus in the state, the producers do not get reasonable price for their produce because of serious deficiencies in the present agricultural marketing system. The present marketing system is placed with certain shortcomings, viz., i) Value chain is too long and fragmented and therefore, particularly in perishables, share of the producer in the consumer's rupee is very low (it is at times as low as 20%), ii) Lack of standardization and enforcement of quality and grades, iii) Insufficient and ineffective services to the farmers regarding inputs and information, iv) Lack of facilities of grading, packing, cold storage and processing, v) Inadequate transparency in marketing and vi) Lack of private sector investment. This results in stress to the farmers (GoM, 2010).

All the above mentioned factors make the agriculture sector vulnerable to the impacts of climate change.

Since most of agricultural production takes place in rural areas and engages people from the marginalized section of the society, poverty and hunger are found to be concentrated in these regions despite the fact that they are the locus of food production. The low coping capacity of the farmer is a significant factor contributing to high vulnerability of the sector to both climatic and non-climatic stresses. More than 50% of the farmers often bypass institutional or formal financial mechanisms and resort to informal credit sources, despite high rates of interest in conditions of declining farm incomes. According to the stakeholder consultations conducted across the state agricultural markets and food supply chains are mainly unorganized and dominated by intermediaries who exploit the small farmers making up the largest proportion of producers. Post-harvest losses occur at a huge scale all through the supply chain due to inadequate storage and transport infrastructure, and wide-spread lack of market information and intelligence among the farmers. Coping responses of farmers to shocks such as droughts are often of the distress type such as selling off of farm assets like livestock or land. Procedures for providing adequate information access on weather and crop management often operate on a delayed mode, lack feedback loops, and often function in isolation. In sum, therefore, agriculture based livelihoods constitute a combination of high vulnerability and low adaptive capacity.

12.2.2 Results from the household survey

Agriculture is the primary employment for the majority of the households[42] surveyed (33%). HHS also gives key insights into the different categories of income generating activities like selling farm produce, dairy produce, wood, fruits and vegetables or being engaged in labour, that the locals are engaged in. Most of the households recorded selling farm produce and being engaged in labour as their primary source of income.

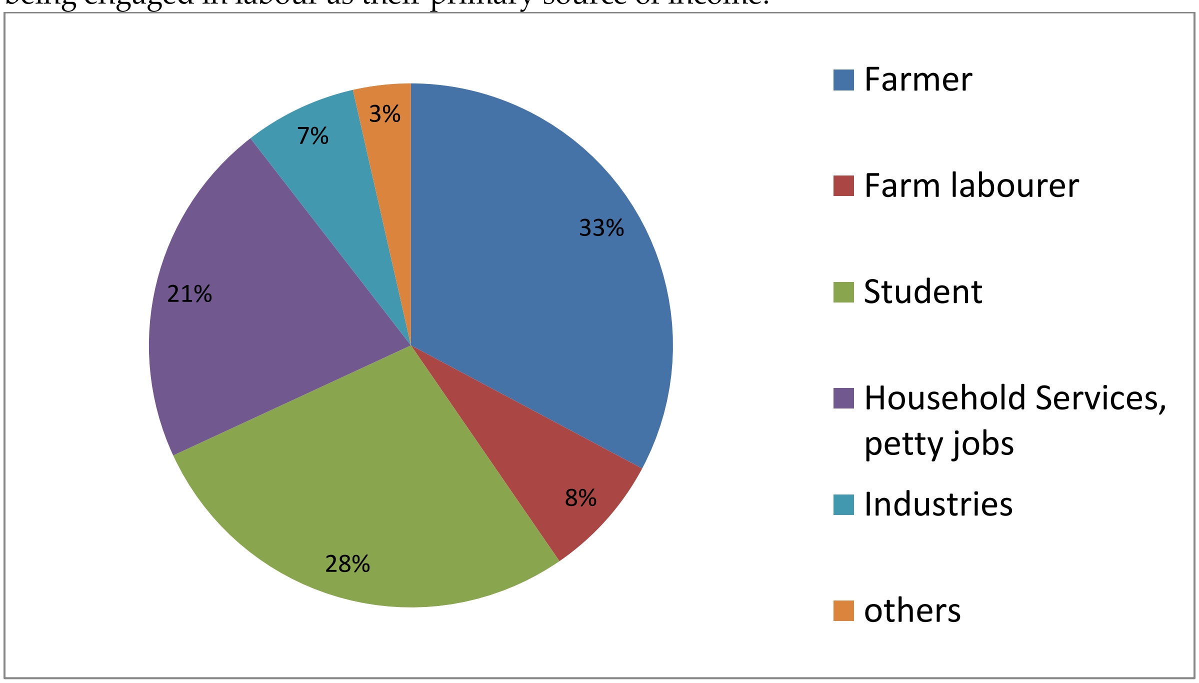


Figure 1: Primary employment activities of the households surveyed; Source: TERI primary survey

[42] In Thane, 67.6% of the households surveyed were engaged in farming while 32.4% were engaged in fishing.

Major sources of income: The following table indicates that selling farm produce is primary source of income for a majority of households in the five districts where more than 50% people are engaged in farm labour, except Buldhana which has only 27.4% people engaged as farm labourers; selling dairy produce figures as substantial alternate source of income for households in Solapur (64.3%) and Buldhana (41.7%).

Table 3: Major sources of income of the households surveyed

	Percentage of households				
Source of income	**Hingoli**	**Nandurbar**	**Solapur**	**Buldhana**	**Gondia**
Selling farm produce	97.7	96.1	98.4	99.2	96.5
Engaged in labour	73.6	60.2	51.8	27.4	66.3
Selling dairy produce	3.1	5.4	64.3	41.7	1.6

Source: TERI Primary survey

Table 4 gives an account of number of sources of income, and indicates that households surveyed in all six districts have more than one source of income, indicating some form of livelihood diversification which can play a significant role in increasing the adaptive capacity of the communities during adverse climatic conditions.

Table 4: Number of sources of income

	Percentage of households (%)		
DISTRICT	**One source of income**	**Two sources of income**	**More than two sources of income**
Hingoli	15.7	65.5	18.8
Nandurbar	26.3	64.5	9.3
Solapur	3.1	62.0	34.9
Buldhana	32.5	42.9	24.6
Gondia	15.1	74.8	10.1
Thane	36.4	56.5	7.1

Source: TERI Primary survey

The households were also asked whether they owned irrigated land or not, the following table gives the percentage of households stating ownership of irrigated land in the six districts. From the table it can be inferred that except for Solapur and Gondia all other districts are highly dependent on rainfall for agriculture which makes them highly vulnerable to any changes in rainfall patterns due to climate change.

Table 5: Ownership of irrigated land

	Hingoli	Nandurbar	Solapur	Buldhana	Gondia	Thane
% of households stating ownership of irrigated land	19.5%	11.6%	66.1%	21.8%	51.8%	20.8% (excluding fishing households)

Source: TERI primary survey

Local perceptions on climate variability and change: Of the total number of houses surveyed 79% noted a decrease in the duration of the rainy season. More than 90% of the households experienced a decrease in the monsoon rainfall and increase in heat waves and more than 65% of the hosuehold stated that there has been a large increase in both the number of dry spells during monsoons and delay in the onset of monsoons. The table below elaborates the perceptions from HHS:

Table 6: Local perceptions on climate variability and change

Perceived changes in climate in last 10-20 years	% households
Changing rainfall patterns	100%
Decrease in monsoon rainfall	94%
Shorter rainy season	79%
Large increase in number of dry spells during monsoon	68%
Large increase in delay in onset of monsoon	66%
Large increase in length of dry spells	60%
Increase in heat waves	98%
Increase in daily max temp	97%
Increase in daily min temp	59%

Source: TERI Primary survey

Sensitivity of crops to climate risks: The households were also questioned on their perceptions about the sensitivity of their crops to climate risks. The following table gives the percentage of households who perceived their crops to be highly sensitive to the mentioned climate risks. More than 50% of the households perceive their crops to be highly sensitive to above average rainfall, high intensity rainfall, dry spells, delayed onset of monsoons and 48% of them perceive their crops to be sensitive to below average rainfall.

Table 7: Local perceptions of sensitivity of crops to climate risks

Perceived high sensitivity of crops to climate risks	% households
Above average rainfall	62%
High intensity rainfall	61%
Dry spells	57%
Delayed onset	55%
Below average rainfall	48%
Heat waves	25%
Above average day temp	15%
Above average night temp	7%

Source: TERI Primary survey

Since the households surveyed are rural households, vulnerability also gets constructed into their lives on the basis of their dependence on fuel wood, whether they fetch water from a distance, pest infestations etc. All these can also have critical bearing for livelihoods of these populations as increase in pest infestations can destroy their crop which is their primary source of income; similarly increase in invasive species can be critical for the crop grown. The high percentage of observed pest infestations shows a need for integrated pest management which is both locally appropriate and culturally adopted. There is also high dependency on fuel wood in all the six case study districts, thereby indicating dependence on forests and impacts of climate change forest can have critical bearings for these communities.
The following table gives the percentage of households with respect to these sources of vulnerability.

Table 8: Source of Vulnerability from HHS

Source of vulnerability	Hingoli	Nandurbar	Solapur	Buldhana	Gondia	Thane
% households collecting fuel wood from forests	99%	74.50%	89%	72.60%	95.30%	66% (both)
% households whose land has been highly impacted by invasive species *(Species of Parthenium)*	60%	40.20%	88.20%	87%	54.30%	83% (only farmers)
% households observing increase in pest infestations	100%	99.60%	100%	99.60%	98%	95% (only farmers)

Source: TERI Primary survey

12.3 Impact of climate variability and change on fisheries based livelihoods in Maharashtra

Maharashtra ranks fifth in marine fish production in India. The state is endowed with 720km coastal length with 1,11,512 sq.km. of continental shelf area up to 100 fathom depth. Fishing activity is regular up to 70 fathom depth. It stretches about 720 km from the River Tapi in the north up to the River Terekhol in the south and encompasses six districts viz. Thane, Greater Mumbai, Mumbai, Raigad (former Colaba), Ratnagiri and Sindhudurg. Table 2 highlights the fish production in the state.

12.3.1 Review of fisheries based livelihoods in Maharashtra

The State has 406 marine fishing villages. Of the total number of villages,159 are in Raigad district, 88 in Ratnagiri, 71 in Sindhudurg, 61 in Thane and the remaining 27 in Greater Mumbai district (CMFRI, 2005). The total number of fishermen households was 65,313 of which 36% were in Raigad district, 27% in Thane, 15% in Greater Mumbai, 14% in Ratnagiri and the remaining 8% in Sindhudurg district. Marine fishermen population in Maharashtra was 319,397. Adult male constituted 35%, adult females 34% and children 31% of the population. Average population per village was 787 and the average family size was 4.89. Trawlers, gillnetters and dol-netters are the main fishing crafts in the mechanized sector (CMFRI, 2005). Nearly 50% of the fisher folk earned their livelihood from acitivities like marketing, making/repairing nets, curing/ processing, peeling, labour and other fishery related activities. Most of the males were engaged in occupation such as labour (32%), making and repairing nets (30%) and while female involvement is higher in marketing (70%) and curing and processing (15%). (Pagdhare and Bhakay, 2012)

Table 9: Fish production in the state of Maharashtra, Source: Department of Fisheries, Government of Maharashtra

Name of District / Year	**Fish Production In Maharashtra (In Metric Ton)**				
	2005	**2006**	**2007**	**2008**	**2009**
Thane	123591	107747	100479	109016	121514
Mumbai	160594	181888	184679	162681	159560
Raigad	40044	39505	32488	33273	39435
Ratnagiri	105069	109055	85099	72318	75122
Sindhudurg	16045	25895	17070	18675	20136
Total	445343	464090	419815	395963	415767

Fishing is often practiced in remote and rural areas where other economic activities are limited and can thus be important engines for economic growth and livelihoods in rural areas with few other economic activities (FAO, 2005). Some fishers are specialized and rely entirely on fisheries for their livelihood, while for many others, especially in inland fisheries and developing countries, fisheries form part of a diversified livelihood strategy. In addition to those directly employed in fishing, there are “forward linkages” to other economic activities generated by the supply of fish (trade, processing, transport, retail, etc.) and “backward linkages” to supporting activities (boat building, net making, engine manufacture and repair, supply of services to fishermen and fuel to fishing boats, etc.) Fisheries may serve as a “safety net” to landless poor or in the event of other livelihoods failing (FAO 2005). In Maharashtra nearly 50 per cent of the fisherfolk earn their livelihood from allied activities like marketing, making/repairing nets, curing/drying, peeling, labour and other fishery related activities. Fishing is traditionally conducted by Mahadeo Kolis (Scheduled Tribe) and Kolis (Backward community) in the most of the fishing villages of Maharashtra. The state has 8,8100 number of fisherman across the five districts. In Maharashtra, the marine fisheries production has started to stagnate in the 1990s and there have only been small increases in the total marine production in recent years. While the relative contribution of commercial fishing vessels to the total marine production is increasing, a relative and absolute decline of catches is being experienced by the small-scale coastal fisheries sector (Tietze et al, 2007). The main reasons for the declining catches and contribution of the small-scale fisheries sector to the marine fisheries production in Maharashtra is attributed to an increasing number of commercial trawlers, use of more efficient and sometimes destructive fishing gear and to the pollution of coastal waters caused by the inflow of agricultural chemicals and fertilizers, industrial waste, storm waters from urban areas, siltation, discharge of waste from towns, discharge of oil from ships and by other sources of pollution. While the role of the small-scale fisheries sector in Maharashtra has declined, the development of alternative livelihoods has been slow and not been able to compensate for lost employment and income. As a result, poverty in coastal fishing communities is a serious problem. The percentage of the population living under the poverty line in the coastal rural blocks of Thane district, Sindhudurg district and Ratnagiri district is as high as 52, 43 and 37 percent. Despite infrastructure improvements in rural areas in Maharashtra related to transport and electricity during the 1990s, local and urban markets, where fish and fish products are landed and sold, often lack basic infrastructure. This includes an absence of concrete floors and ceilings; a lack of storage, cold storage and fish handling and transport facilities; an irregular supply of electricity and lack of generators to be used during power outages; a lack of supply of clean and safe water; a lack of drainages and solid waste disposal facilities and a lack of hygienic facilities such as bathrooms and latrines.

The impact of climate change will further act as an additional stressor to the above mentioned challenges in the fisheries sector. Daw et al (2007) highlight that climate change will have a direct impact on the livelihoods of the people dependent on it (Figure 2). However, Salagrama (2012) notes that the level of perception about impacts of sea-level rise on fisheries is very limited. More recent work by CMFRI in Maharashtra indicates that some 75 coastal villages are vulnerable to inundation due to a projected 1m rise in sea level, expected to happen over 20-50 years (Dr VV Singh, pers. comm). Sea-surface temperature is considered to be an indicator of ocean variability as well as more complex ocean processes. As with sea-level rise, the fishermen are unable to perceive a rise in sea temperature as a result of climate change. Vivekanandan et al. (2009) have reported warming of the sea surface along the entire Indian coast wherein the SST increased by 0.2^{o}C along the northwest, southwest and northeast coasts during the 45-year period from 1960 to 2005. In Maharashtra, it is reported that temperatures have increased both at the surface and even more at the bottom. . Also extreme precipitation events have been on an increase that has had catastrophic effects on fish-drying operations in Maharashtra. Seawater intrusion into the villages as reported by Salagrama (2012) is a perennial problem of increasing intensity in places like Satpaty and Vasai in Maharashtra (Salagrama (2012). All these combination of impacts make the livelihoods dependent on fisheries highly vulnerable to the current and future impacts of climate change.

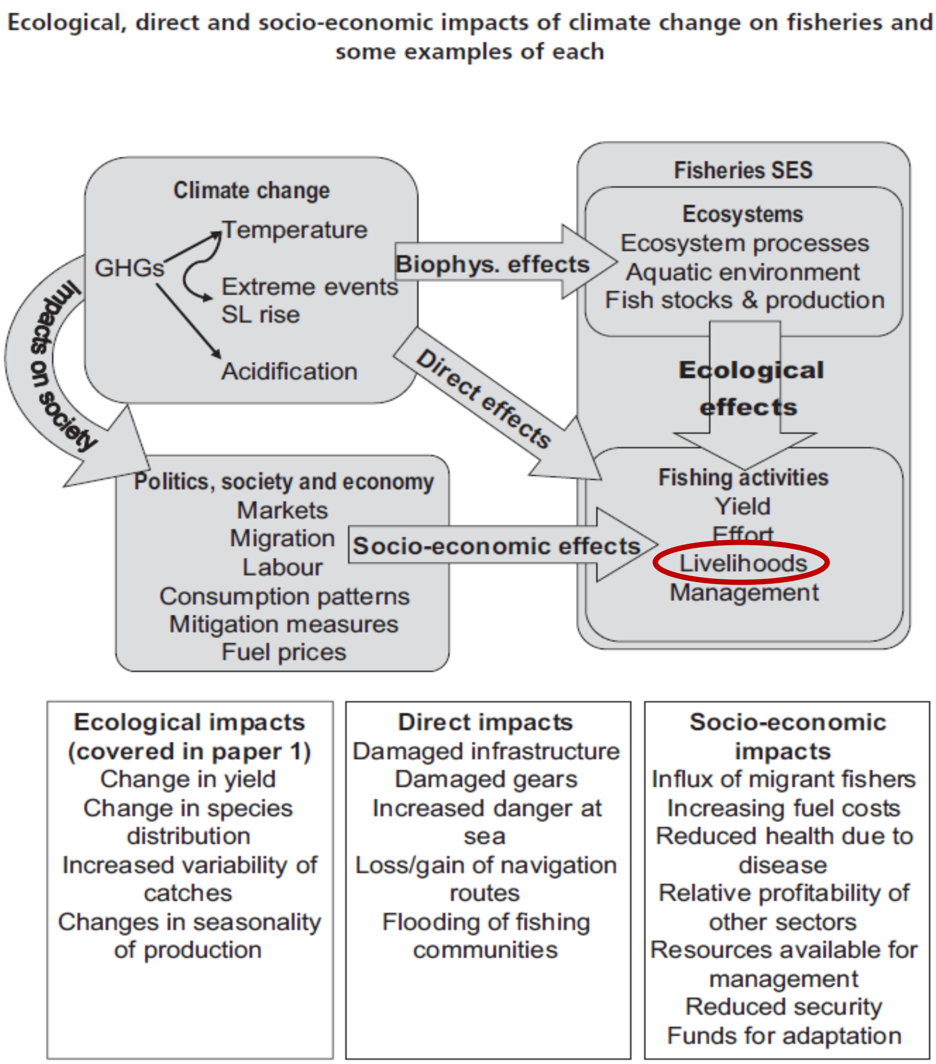


Figure 2: Impacts of climate change on fisheries, Source: Source: Daw et al., 2009

According to Vivekanandan (2011) the small-scale traditional fisheries will be the most vulnerable to climate change. He further notes that governance and co-management systems that are based, inter alia, on an understanding of ecosystem health and thresholds, partnerships, stakeholder inclusiveness, equity and sustainable livelihoods should also be regarded as vital elements of climate change adaptation planning for small-scale fisheries.

12.3.2 Results from the household survey

Amongst the six districts selected as case study sites, only Thane has people engaged in fisheries for livelihood generation. Therefore the following results present the perceptions of fisherman in Thane district.

Perception on changes in climate by fishing households: The following table gives the percentage of households who have perceived changes in the climate over the last 10-20 years. All the fishing households surveyed have experienced a change in the rainfall pattern with 56% of them reporting an increase in the number of high intensity rainfall events. 90% of the fishing households also perceived an increase in heat waves while 39% perceived an increase in storms in the last 10-20 years.

Table 10: Perceived changes in climate by fishing households

Perceived changes in climate in last 10-20 years	% fishing households
Changing rainfall patterns	100%
Increase in total yearly rainfall	91%
Increase in monsoon rainfall	83%
Longer rainy season	72%
Increase in number of high intensity rainfall events	56%
Increase in heat waves	90%
Increase in daily min temp	80%
Increase in daily max temp	70%
Increase in storms	39%

Perceived sensitivity of fish produce to climate risks: The following table gives the perceived sensitivity of fish produce to climate risk. More than 50% of the fishing households perceive that the fish produce is sensitive to above or below average rainfall, increase in heat waves, and increase in daily min. and maximum temperature while 40% of the households perceive that the fish produce is sensitive to high intensity rainfall events.

Table 11: Local perceptions on sensitivity of fish produce to climate variability and change

Perceived sensitivity of fish produce to climate risks	% fishing households
Above average rainfall	70%
Below average rainfall	59%
Increase in number of high intensity rainfall events	40%
Increase in heat waves	85%
Increase in daily max temp	58%
Increase in daily min temp	52%

Source: TERI primary survey

12.4 Impact of climate variability and change on forest based livelihoods in Maharashtra

With almost 60116 square kilometers of land area under forest and tree cover, Maharashtra is a state that is rich in forest resources. Gadchiroli, Amravati and Chandrapur are the districts that have the maximum area of forest cover (Figure 3).

12.4.1 Review of forest based livelihoods in Maharashtra

The state of Maharashtra has 20.13% of its total geographical area under forest cover. Forests provide major products like timber, firewood and minor products like bamboo, tendu leaves, gum etc. All these forest produce are of great value in terms of generating revenue and contribute to GDP of the state as well as providing livelihood to local people.

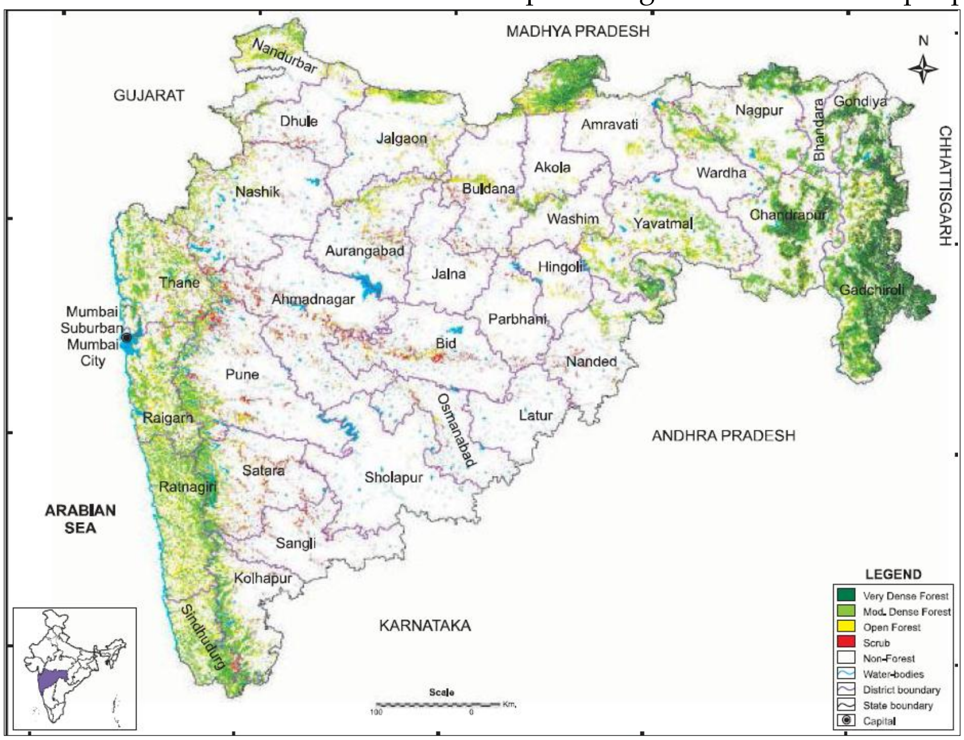


Figure 3: Forest Cover Map of Maharashtra, Source: India State of Forest Report, 2011, Forest Survey of India

As per the Economic Survey of Maharashtra, 2008-09, the production and value of forest produce in Maharashtra is as follows:

-

(Rs in crores)

Forest Produce	Unit of Production	2007-08		2008-09	
		Production	Value	Production	Value
(A)**Major Forest Produce**					
Timber	LCM	1.49	214.2	1.88	174.8
Firewood	LCM	4.61	33.1	4.32	69.1
Total (A)			247.3		244.0
(B)**Minor Forest Produce**					
Bamboo	LMT	1.57	23.9	2.85	26.4
Tendu	LSB	7.67	94.0	7.39	72.0
Grass	MT	6,279	0.3	521	0.2
Gum	Qtls.	5,026	1.5	700	0.0
Others		--	2.2	--	10.6
Total (B)		--	121.8	--	109.3
Total (A + B)			**369.1**		**353.2**

Figure 4: Production of Major and MinorForest Products in Maharashtra , Source: Office of the Principal Chief Conservator of Forest, GoM (Economic survey of Maharashtra 2008-09); Note: LCM: Lakh Cubic Meter, LMT: Lakh Metric Tonnes, LSB: Lakh Standard Bags

They depend on forests for timber, poles, firewood, bamboo, fodder, grass, fruits as well as a number of non-wood forest produce for household consumption and sale. Local artisans make their living by making baskets, mats, dholis, etc. from bamboos. They sell most of their products locally. Local people get gainful employment during tendu leaf collection season from the last week of April to mid-June. The distrcit of Gondia is also a major centre of the bidi manufacturin where a considerbale number of people are employed and again depdent on forest for their raw materials. Some forest regions are suitable for lac cultivation, mainly on the Palas trees. Villagers living near forests collect a variety of non-wood forest produce such as Moha flowers, Moha fruits, charoli seeds, gum, honey, etc. for their household consumption and sale.

According to Ravindranath (no year), climatic conditions unsuitable for the existing biodiversity may metamorphose 21% of Maharashtra's forest vegetation by 2030. The study assesing the impact of global warming and climate change on forests, their types, distribution and productivity using the dynamic global vegetation model, notes that about 45% of the forested areas in the state will undergo change by 2080. These changes in the forests will have a significant adverse impact on the lives and livelihood of people who depdent on forests and its products for their survival.

12.4.2 Results from the household survey

As mentioned in the above section that favourable climatic conditions play a significant role in productivity of forest products and consequently on the livelihoods of local people. According to the HHS, 83% of the surveyees reported that they collect fuel wood from the forests. Change in distribution of forest can affect these household considerably. Most of the households in Hingoli, Thane, Solapur and Nandurbar have reported that use of new technologies like solar lights, cook stoves etc. would provide an alternative solution to the crisis ensuing from depletion of firewood.

While looking at the percentage of households reporting a decrease in forest produce, the range varies from 30-100% for tendupatta, 48-100% for Mahuwa flowers, 84-99% for honey and 49-99% for Charoli over the districts. Collection of these forest product contributes to the livelihood income of these surveyees and a notes decrease can imapct these households significantly .

Table 12: Vulnerability of forest dependent households

Collection of fuel wood from forests	**82.83%**
Decrease in forest produce	
Tendupatta	30-100%
Honey	84-99%
Mahuwa flowers	48-100%
Charoli	49-99%

Source: TERI primary survey

In Solapur, most of the surveyees have reported decline in honey followed by *charoli* and *mahuwa* flowers. In Buldana, highest proportion of surveyees have reported decline in availability of honey followed by *mahuwa* flowers. In Thane, 80% of the farmers and 95% of the fishermen have reported decline in availability of honey.

12.5 Household level coping with climate change

Households employ a number of coping mechanisms in order to address climate variations and uncertainty, such as diversification of crops and sources of income, migration, collection of wild fruits, switching to non- farming activities, selling assets and reliance on remittances and social networks. Most households employ a combination of responses to the impacts of climate on their livelihoods. The household survey gives key insights into the coping mechanisms adopted by the households in the 6 case study districts.

The farming households were then questioned on the coping mechanisms employed by them to deal with adverse climate situations. The responses have been segregated into two categories – *distress and non-distress coping mechanisms*. Selling available stock of food grains, cattle and migration are included in the *distress* category while and shift in cropping patterns/ use of salt tolerant varieties, shift to less water intensive crops/ use of drought resistant crops, more inputs of fertilizers, pesticides, use of HYVs in the *non-distress* category.

Distress coping options: The table below highlights that migration as a coping mechanism is employed by a small fraction of households in all the districts. It emerges as the least preferred coping mechanism across all districts. The most prominent coping option is selling of available stock of food grains for all the six districts in the households surveyed. While 57.1% households in Hingoli and 83.9% in Solapur resorted to selling cattle as a coping mechanism. This shows that communities resort to selling of their assets as a distress coping mechanism.

Table 13: Distress coping mechanism employed by households

Distress Coping Mechanism employed	Hingoli	Nandurbar	Solapur	Buldhana	Gondia	Thane
% of households						
Sell available stock of food grains	93.5	90.7	75.3	88.9	93.4	59.1
Sell cattle	57.1	22	83.9	20.2	30.6	8.2
Migration	21.8	15.1	22.4	8.7	24.4	-

Source: TERI primary survey (For Thane only non- fishing households were taken)

Non-distress coping options: the below table highlights that in all districts farmers use a combination of non-distress coping options in response to climate stress. With respect to shift to less water intensive crops, *Mahabij* is one of the top choices of surveyees. Nearly 11.7% of surveyees mentioned *Mahabij* as their choice for less water intensive and drought resistant variety. Other popular choices were *Ratna, Sweta, Manas.* All options are used significantly by all households except in Nandurbar where the option of shifting to less water intensive crops/ use of drought resistant varieties are adopted by a meagre 29% households.

Table 14: Non distress coping mechanisms employed by households

Coping Mechanism employed	Hingoli	Nandurbar	Solapur	Buldhana	Gondia	Thane
	% of households					
shift in cropping patterns/ use of salt tolerant crops	91.2	54.4	90.6	96.8	70.2	82.5
shift to less water intensive crops/ use of drought resistant varieties	73.6	29	88.6	64.3	74	93.6
more inputs--fertilizers, irrigation, pesticides	93.5	96.5	97.3	97.2	95.3	95.9
Use of HYVs/ disease resistant varieties	93.5	96.5	96.1	98	94.2	94.2

Source: TERI primary survey (For Thane only non- fishing households were taken)

The following table looks at the percentage of households employing the various coping mechanisms across the three land holding categories. Land is an important asset. From the table it can be inferred that 38% of the farmers belonging to the category of owning 'more than 10 acres' of land irrigate land in case of drought which indicates availability of resources to do so. Similarly an increase in use of farm inputs, shift in cropping patterns, use of HYVs etc. is also highest in the category owning 'more than 10 acres' of land, thereby again indicating the availability of resources. As the landholding size increase the ability to irrigate land also increases. Selling food stock (80-96%) is a more preferred option than selling of valuables (13-26%) across the landholding categories. Amongst all coping options, migration emerges as the least adopted coping strategy by the households surveyed.

Table 15: Coping mechanisms across the three land holding categories

	Coping mechanisms employed							
land holding category	irrigate land in case of drought	Sell land and valuables	Sell stocks of food grains	shift in cropping patterns/ use of salt tolerant crops	use of more inputs-irrigation, pesticides etc	use of HYVs/ disease resistant varieties	Migration	Sell cattle
	% of households							
<3 acres	15.64	13.08	80.90	73.83	95.34	94.29	17.74	35.19
3-10 acres	21.03	19.12	87.79	86.32	97.06	97.21	14.56	40.59
>10 acres	38.00	26.00	96.00	93.00	96.00	95.00	17.00	52.00

Source: TERI primary survey (For Thane only non- fishing households were taken)

12.6 Action plan

12.6.1 Adaptation Action: Increasing Storage Capacities through Energy Efficient Cold Storage Systems

Action Category: Technology Development and Deployment/capacity building
Geographical Scale: Vidharbha and Marathwada regions & village/ community based
Community Focus: Rural households
Rationale: Maharashtra has a prominent position on the horticultural map of India with more than 15 lakh hectares are under different fruit crops. The state has a 14.5 percent share in the country's fruit production and ranks first amongst all the states; and contributes 27 per cent in area and 21.5 per cent in production (Planning Commission, 2007) . Fruit-production during 2008-09 constituted 30.27 percent of the total agricultural produce (food grain and horticultural produce) in the State. The percentage of fruits in the total horticultural production of Maharashtra during 2009-10 was 61 percent (FICCI, 2011) . The State is the largest exporter of thompson seedless grapes, alphonso mangoes, onions and long stem cut flowers besides being the leading producer of Mandarin oranges, grapes, pomegranates, sapotas, sugarcane, alphonso mangoes.

Cold storage facilities for fruits and other horticulture crops is a fundamental requirement for ensuring minimal damage to the produce and for fetching good prices in the market for the producer. However, poor infrastructure including lack of integrated cooling facilities (cold chain) is a concern for the horticulture sector and entire food processing industry in the state. The Ministry of Food Processing in India has identified refrigeration and cold storage facilities as the weakest link in the whole value chain. Lack of proper cold storage facilities has led to the following major consequences:

a) Excess produce that floods the market and results in oversupply or gets wasted
b) An artificial scarcity is created during non-harvesting period

In Maharashtra, it is estimated that as much as 30 - 35 % of fruits and vegetables production is lost on account of lack of adequate post-harvest infrastructure. Agricultural produce of the farmers does not get remunerative prices due to lack of grading, storage and proper packaging and in turn there are huge post-harvest losses. Amongst these lack of cold storage facilities for fruits and other horticulture crops has emerged as important need amongst the farmer communities. Cold storage at the farm gate reduces wastage, reduces cost of transportation to centralised units and increases the shelf life of the product, thus giving farmers more options to take the right marketing decisions. Around 460 cold storages have been set up in Maharashtra in the public, private and co-operative sectors with a capacity of 5.64 lakh MT, mostly around Thane, Nashik and Mumbai (GoM, 2010) .

The focussed group discussions with communities in all 6 case study districts along with semi structured interviews with district officials brought out the need for cold storage factices as a primary requirement for climate proofing their farm products along with fetching good prices in the market. FGDs highlighted challenges like time and cost of transportation to cold storage facilities which are not wide spread but sparse in the region, secondly shelf life of fruits and vegetables is very short and maintaining the right temperature and humidity is critical to retaining the quality of the product. As also brought forward from the HHS, most of the household in the case study sites are engaged in agriculture as primary livelihood activity, hence increasing cold storage facilities can contribute significantly to increasing the adaptive capacity of farmers in the region.

Also very often farmers have to resort to distress selling due to limited shelf life of the produce and absence of access to even short term cold storage facilities. As a result the small and marginal farmers face difficulty in getting good returns on their produce. The role of cold storage is of prime importance for fetching good prices for agriculture produce particularly fruits in the international markets. Cold storage facilities for perishable produce will not only reduce glut in the market and avoid price fluctuation but it also increases the shelf life and quality of agri-produce. Thus, in turn the producer would get remunerative prices for their produce.

Furthermore villages in the state which are un-electrified and even electrified ones have erratic power supply. Hence there is a need for small cold storage facilities that are not dependent on grid electricity, but are a back up to the grid, to temporarily store the farm produce till market prices are more amenable to small farmers. Therefore a given the importance of horticultural crops in the state and need for cold storage an energy efficient cold storage system is proposed which can cater to the needs of the farmers for storage while mitigating the impacts of climate change. Such a system will also contribute in creating livelihood opportunities and local entrepreneurship for the rural household communities while also working as a back up to the grid system.

Key Components:
Maharashtra has an agricultural / agro -industrial surplus biomass with a potential of about 781 MW distributed through the state. The Marathwada and Vidharbha regions of Maharashtra which are blessed with perennial solar energy and lots of surplus biomass resource, developing a solar-biomass powered cold storage in this region can help meet this shortage using abundantly available renewable energy that is best suited for rural/decentralised deployment.

The proposed strategy aims at value addition from agricultural produce by minimization of wastage across the food processing chain by development of infrastructure for cold storage of agro-food produce to fill in the gaps of supply chain from farm to consumer, and promotion of investment in all these fields. The objective is also to increase participation of entrepreneurs and farmers in food processing and related sectors, creating new employment opportunities, and increasing incomes, particularly of the rural population.

The cold storage system proposed, which comprises of 15KW vapour absorption machine coupled with 50 KWe biomass gasifier and a field solar concentrating collectors. The biomass gasifier produces synthesis gas using locally available woody biomass, which is then used to run an engine-generator to produce electricity. The waste heat from the biomass gasifier along with heat energy from solar concentrating collectors is utilized by the VAM to cool the cold storage chamber. Since the cold storage can be cooled to 00C, a wide variety of fruits, vegetables and horticulture produce can be stored there. The electricity generated in the system is enough to power domestic, community as well as productive loads in a typical village.

Expected Outcomes:

The proposed system would work on the concept of using indigenously produced biomass and solar energy which would help in setting up a small cold storage facility at a village unit as compared to commercial units at centralised locations. This would give farmers the easy access to cold storage facility and reduce the cost of transportation to centralised locations. Successful implementation of such a system will help in saving both the agricultural produce, give more security to the farmers and also provide for village electrification. Besides providing cold storage facilities as means for rural economic development, the system will ensure electricity supply to rural household communities. The socio-economic impacts of this would be multi-fold namely:

i. The system so developed would be a self sustainable unit which has co-benefits like providing access to electricity from clean sources of energy thereby reducing dependence on fossil fuels/kerosene and contributing to climate change mitigation

ii. Use of electricity for income enhancing activities like local entrepreneurship development and irrigated farming

iii. It will provide for increased hours for study and social interaction and improved quality of life.

Implementation:

Time Frame: 3 years to set up energy efficient cold storage units in every village

Links With Ongoing Government Initiative: National Horticulture Mission, Maharashtra Maharashtra State Agricultural Marketing Board, Pune

Nodal Department: Department of Agriculture, Maharashtra

12.6.2 Adaptation Action: Insurance and Linked Strategies

Action category: Research, Technology deployment and Capacity building; Region specific; Short term; Rural/urban both

Rationale: The State has been actively participating in centrally sponsored crop insurance schemes like the Modified NAIS. About 26 lakh farmers are covered under various crop insurance schemes in Maharashtra, with Rs 83 crore provided under the 2011-12 state budget for insurance premium subsidy. However, within the state participation has been limited to selected districts. Further, participation has been mostly promoted by their requirement for loan. As such, income loss related to crop failure is not insured. State shares the premium subsidy (with the central govt.) and therefore compensation in other monetary form due to climatic fluctuations or disasters may be difficult to finance if we do not prepare a “state contingency fund[43]”. The State has certain unique insurance programmes like for livestock, population below poverty line, farm workers, etc.

Weather Based Crop Insurance Schemes (WBCIS) are being implemented in the state in collaboration with ICICI-Lombard, IFFCO-TOKIO, M.S Cholamandalam General Insurance Companies, besides the Agricultural Insurance Corporation. Weather-indexed insurance products have been developed for different crops and pilot tested during the last five years. They have tremendous potential to increase the adaptive capacity of farmers as quicker payouts enable faster recovery from rainfall failure. However, the scaling up of weather-indexed insurance will be possible only if the costs of administration are reduced considerably and the inherent biases in this instrument are addressed. One, all forms of insurance have an adverse selection problem, which can be reduced by providing prompt crop management advisories to farmers to take preventive measures. For instance, the mKrishi initiative implemented by Tata Consultancy Services uses mobile phones to conduct disease surveillance and to connect farmers to experts who provide customised disease management solutions. Second, accurate triggering of payouts requires weather data that is as close as possible to the insured farmers’ fields, which requires the expansion of the automatic weather station network. The experience of the HDFC Ergo General Insurance promoted programme may be utilized to enhance the index based weather insurance. The immediate requirement is to promote public-private partnership and explore cases where State has to work and plan independently.

Key components of the action:

1. Extension of MNAIS to more villages and suitable incentives to motivate participation of non-loanee farmers. AIC has observed that the coverage of Non Loanee Cultivators is the highest in Maharashtra as the compulsion on NAIS being mandatory for the loanee farmers has been relaxed.

[43] The State Government have created a Rs 550 crore fund for overcoming water and fodder scarcity, drought relief, in various areas. The fund currently capped at Rs. 150 may be progressively revised. States like Karnataka, Bihar, Meghalaya, among many others maintain such funds, having direct or no linkage with National Calamity Contingency Fund (NCCF or NFCR).

2. Extension of FPAIS to include more perils (especially those related to weather related events)

3. Emphasis on micro-insurance: Assess the progress of HDFC Ergo Pilot Index based insurance policy. Participation in Weather Based Crop Insurance Scheme (implemented in selected states on a pilot basis since Kharif 2007)

4. Identify the vulnerable districts due to natural hazards drought and earthquakes. Innovative infrastructure solutions to be aided by risk financing measures. Example: National drought insurance in Malawi; technology to keep track of livestock levels by using freely-available satellite data to supplement livestock insurance in Kenya, Horn of Africa Risk Transfer for Adaptation Program in Ethiopia, Drought index insurance for vegetables in China, or even learning's from the Australian drought policy, among others.

Expected outcomes:

1. The component will not only help identification of farmers/households most affected by crop failure but also ease disbursement of monetary compensation from the State. If participation of non loanee farmers increases, subsidy amount (in shared premium) may be initially large but it would be less compared to post disaster financing. These would also feed into the overall objectives of financial exclusion – banking plus insurance. Risk financing should aim at inculcating risk management (traditional and modern) practices.

2. Financing disaster mitigation (or prevention)

Implementation:

- At least five years in continuum

- MNAIS, FPAIS, AABJ, LIP and WBII

- Directorate of Agriculture, Relief and Rehabilitation Division under Revenue and Forests Department, Maharashtra Livestock Development Board, India Meteorological Department

- Establishment of automated weather stations in regions where Weather Station density is less/poor (needed for further enhancement of the weather based index insurance programme), infrastructure for dissemination of weather related information, state/central govt. schemes, promotional activities and guidelines for credit/insurance facilities, etc. through FM/Radio/TV in vernacular languages in dialects specific to the region. Utilization of local decentralized institutions, KVKs of ICAR in the State (42 in numbers), etc.

Choice criteria:

- The aim is to not only facilitate immediate credit/risk financing needs but also strengthen adaptive capacities of farmers and the most vulnerable section of the society. Integration of risk management schemes along with risk preventive infrastructure go hand in hand to tackle the adversities of climatic fluctuations

- Priority is to extend the facilities in a phased manner, monitoring and review of progress of polices on a quarterly basis (season wise especially for crop insurance). To start with the district/region where penetration of such policies in equivalent to zero. For district/region already under the programmes, set smaller growth targets of around 10% annually (keeping in view the additional finances required). Periodic impact evaluation by a not-for profit agency.

- Some of the strategies may be implemented under public-private partnership (PPP). The state may allow "contract farming" and concessions/exemptions for firms/industry participation in State effort towards enhancing the overall objectives of financial inclusion. It would be beneficial to include micro-institutions (like MFIs, Gram Sabhas, etc.) for delivery of services (say, payment of claims and compensation) where banks/post-offices are unavailable/not accessible.

13. Health impacts of climate change and adaptation in Maharashtra

13.1 Overview of current status and recent trends in public health sector of the State

Compared to many other states of the country, Maharashtra has encouraging statistics with respect to many vital health indicators (Table 1), having immense scope for improvements in various aspects of public health and health care. With respect to fertility indicators, the Crude Birth Rate (CBR) in the State is much lower than that of India on an average. In terms of important mortality statistics, the Crude Death Rate (CDR) in the State has been showing a steady decline over the years and is significantly lower than the average for India. Better health services are expected to further reduce the CDR in the State (Health Status Maharashtra 2009).

Table 1: A comparison of some important Health Indicators between Maharashtra and India

State	CBR*	CDR*	IMR*	Life expectancy#	
				Male	**Female**
Maharashtra	17.6	6.7	31	67.9	71.3
India	22.5	7.3	50	65.8	68.1
* SRS 2009 (SRS Bulletin Jan 2011); # Population projections by RG India (2001 -2026)					

Source: Website of Department of Health, Government of Maharashtra

Infant Mortality Rate (IMR), which is an important indicator of both child health and overall human development, has also been on a continuous decline in the last two decades and is much lower than the country average. However, the steep reduction in state IMR has been mostly contributed by reduction in IMR in the urban areas of the State, while in the rural areas the decline has not been striking, thus revealing a gap that needs to be addressed. Moreover, the nutritional status of children continues to present a challenge, though malnutrition rates have decreased over the years (Table 2). Similarly, current Maternal Mortality Rate (MMR) in Maharashtra at 130, though is as low as half of the country average, is somewhat still far from the expected 2010 target of achieving a MMR lower than 100 per 100,000 live births. Despite the universalization of immunization services in the country, cases of vaccine preventable diseases such as measles, diphtheria and pertussis are also significantly high in the State. Likewise, an increasing trend is seen in case of Non-Communicable Diseases (NCDs) such as *Asthma*. But overall, the life expectancy (both for males and females) in the State is better than the Indian average and comparable to many progressive states of Southern India such as Kerala and Tamil Nadu.

Table 2: Trend in Nutritional Status of children (%) below 3 years of age in Maharashtra

	Stunted	Wasted	Underweight
NFHS-1	40.9	23.1	51.4
NFHS-2	39.9	21.2	49.6
NFHS-3	37.9	14.6	39.7

Source: Health Status Maharashtra, 2009

In terms of health services, Government of Maharashtra has made considerable efforts in providing affordable and accessible health services to the communities. As per government norms, a minimum of one health Sub-Centre (which is the lowest tier in the rural health care delivery infrastructure in India) is to be made available for a population of 3,000 in tribal areas, and 5,000 in non-tribal areas. As per the 2001 Census statistics for the State, the average tribal population per sub-center was around 2,620 while average rural population per sub-center was around 5,296. Similarly, in terms of Primary Health Centers (PHCs), currently the average population per tribal PHC is around 17,004 and for rural PHC it is around 30,850, both within the prescribed norms. These PHCs have a critical role in the public health care system of the State, being engaged in health services such as the prevention and control of epidemics, water quality testing, management of malnutrition, health education, referral services etc. Though average statistics indicate compliance to established norms, it is important to mention that wide disparities are seen in districts with respect to coverage and availability of these critical health care facilities.

In terms of higher order health care, the total number of hospitals and consequently the number of available hospital beds has increased by about 50% in the last 25 years or so. However, this increase has been predominantly concentrated in the urban areas of the state, with rural health infrastructure growth showing an increase at a modest rate. The number of doctors and nurses available in the State has also shown significant growth in the last 25 years (Health Status Maharashtra, 2009). A multitude of supporting institutions such as the State Health Transport Organization, Bureau of Health Intelligence & Vital Statistics, and multiple Public Health Laboratories are also playing a critical role in increasing the efficiency of public health care delivery in Maharashtra.

13.2 Key determinants of health vulnerability in the State

High Growth Rate of Population and Urbanization

Maharashtra, with a 9.29 percent share of India's total population, is the second largest State in terms of population size exhibiting a growth rate if 15.99 percent during 2001-11.Districts like Thane and Pune have registered high growth rates (35.9% and 30.3 % respectively) in the last decade. The current growth rate has increased the population density of the State to around 365 persons per sq. km as compared to 315 in 2001. Mumbai (Suburban) and Mumbai rank highest in terms of population density with a recorded density of 20,925 and 20,038 persons per sq. km in the 2011 Census (Census of India, 2011). High growth rates together with fast urbanization of many districts and high poverty levels can increase the pressure on natural and socio-economic resources (including access to basic civic amenities such as clean drinking water and adequate nutrition), consequently imposing additional strain on health care services and infrastructure.

Existing Inequality in Health Status of Population

Socio-economic inequities in society are one of the major causes for existing inequities in health status of the communities (CEHAT, 2008). As per district statistics, a critical development indicator such as the IMR shows considerable inter-district variation, from being as low as 20 in the district of Sangli to as high as 48 in Washim. As mentioned previously, the improvements in the state IMR has been mostly due to reduction in urban IMR, while in the rural areas progress has been less striking. The distribution of education, which is an important determinant of health awareness and health seeking behavior of people, is also extremely skewed, particularly in the rural regions and especially among the socially backward sections of the society. Small isolated communities, in general, suffer from inadequate availability of health services. As per 2001 Census, around 22000 small villages with a population less than 1000, constituted more than half the total villages in the State. Of these around 2900 villages had a population of less than 200, thereby posing challenges in reaching out to these small communities with adequate health care facilities (Health Status Maharashtra, 2009).

Poor health and vulnerable status of tribal communities and urban poor

Fifteen districts in the State have a sizeable population of different tribal communities who are considered as particularly vulnerable groups, largely due to the physical exclusion they suffer due to their habitation in relatively inaccessible regions such as the mountains and forests. A wide variation is evident with respect to the coverage of tribal population by health care facilities. For instance, coverage by health sub-centers is sufficiently high in tribal areas of Gadchiroli, Chandarpur and Gondia, whereas the condition is dismal in other districts such as Jalgaon and Yavatmal. Kate (2001) summarizes some of the primary health problems concerning the tribal populations in the State:

- Deficiency of essential components in diet leading to malnutrition, protein calorie malnutrition and micronutrient deficiencies (Vitamin A, iron and iodine) are common.

- Water-borne and other communicable diseases such as Malaria and Tuberculosis are widespread. Gastrointestinal disorders, particularly dysentery and parasitic infections, are very common leading to marked morbidity and malnutrition.
- Superstitions particularly related to health problems which affect health care seeking behavior in people.
- Extreme poverty and economic backwardness which limits access to health services and other determinants of health such as education.

Similarly, poverty and other forms of social disadvantage translate into poorer health status of the urban poor and slum dwellers (Madhiwalla, 2007). These urban poor are exposed to various kinds of environmental pollution and epidemics due to poor living conditions, commonly cramped pathogen-prone neighborhoods, and limited access to basic civic services such as safe and adequate water supply, sewerage and drainage, sanitary toilets and solid waste disposal facilities (Karn and Harada, 2002).

Deficiencies in public health care system

Despite appreciable economic growth in the State, health indicators have not kept pace with this growth. Though the public health care network is continually being expanded, a major reason for slow progress in health scenario is the unequal distribution of health care resources within the State. For instance, urban-rural divide is evident from the fact that just around one-eighth of all hospitals are located in the rural areas, with total number of hospital beds available in urban areas being almost 20 times as high as the number of beds available in rural areas (Health Status Maharashtra, 2009). Although urban hospitals (whether public or private) are also used in significant numbers by those living in villages, the latter face various adversities in accessing these healthcare facilities located in urban areas. Another indicator that highlights dependence of people on private health care is the huge average out-of-pocket expenditure in the State, both for OPD and IPD services. This dependence is more pronounced in the urban areas. An increase in health spending under a climate change scenario requires that focus be shifted from private to public spending so as to reduce the burden that may fall on households with low incomes or which are below poverty line as capacity to cope with climate disasters and there after effects is already low in this section of society.

13.3 Incidence of climate-sensitive diseases and potential impacts of climate change on human health

Incidences of climate sensitive diseases such as vector- and water-borne diseases are widespread in the State. Vector-borne diseases are probably the most sensitive to changes in climate parameters. The statistics for malaria show that the cases have almost been on a continual rise since 2005-06 (Figure 2). Since 1997, the World Bank assisted Enhanced Malaria Control Project was being implemented in 16 tribal districts of the State and since 2005-06 three more districts viz. Ratnagiri, Sangli and Akola were included in the project. District Malaria Control Societies have been established for the implementation of the project in tribal area of the district. A State Malaria Control Society has also been established for more active implementation of the project. In 2003, The National Vector Borne Disease Control Programme was launched and includes monitoring and management of all vector borne diseases like Malaria, Filaria, Dengue, Japanese Encephalitis, Plague, Kala Azar etc.

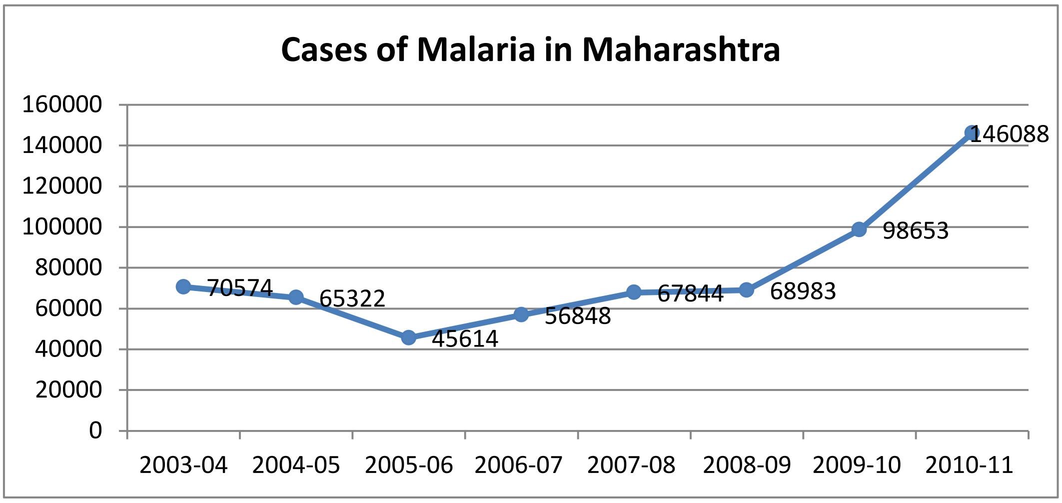


Figure 1: Malaria Situation in Maharashtra State (2003-04 to 2010-11)

There is a slight decrease in the number of Dengue outbreaks and attacks in the recent years. However, continued surveillance is critical (Table 4). Also, outbreaks of Chikungunya fever have occurred in the State in recent years, though the number of cases has shown a continually decreasing trend with zero casualties.

Table 4: Trend of Dengue Fever in Maharashtra (2004-05 to 2008-09)

Year	Outbreak	Attacks	Deaths
2004-05	432	3186	22
2005-06	227	3706	56
2006-07	190	11053	27
2007-08	160	4243	25
2008-09	189	4073	21

Source: Health Status Maharashtra, 2009

Inadequate availability of water, poor water quality at source, ill-maintained water lines, unsafe sanitation practices and lack of awareness about good sanitation practices, personal hygiene and primary health care are some of the key factors responsible for the common and widespread health risks associated with consumption of pathogen infested drinking water in rural habitations. As a result, water borne diseases are also a big concern in the State. Projected change in climate parameters are likely to influnece the burden of climate sensitive diseases in the state.

Climate change may adversely impact human health by increasing the risk of exposure to vector, water and food-borne diseases, aggravating malnutrition and increasing injuries and deaths from extreme rainfall events and thermal stresses (IPCC, 2007). However, a number of non-climate factors such as population growth and demographic change, access to clean water, adequate nutrition and sanitation facilities, improvements in health care, and disease prevention and control programs have tremendous influence on either reducing or

aggravating these climate induced impacts. Very few studies have been carried out in the Indian context to study the impacts that climatic changes may have on population health. However interest in this field is increasing now and more evidence is being generated.
Preliminary assessments carried out for India's first National Communication to UNFCCC (GoI, 2004) show that under the IS92a scenario, the severity of droughts and intensity of floods in various parts of India is likely to increase. The assessments project that the basins of Narmada and Krishna are likely to experience seasonal or regular water-stressed conditions while the river basin of the Godavari is projected to experience water shortages in a few locations. A change in the water availability situation in the State can have serious implications for health outcomes such as water-borne and nutrition related diseases amongst others. Water availability is also fundamental to food security. Thus, impacts on water sector can be expected to have a cascading effect on food production thereby affecting food security and nutritional status of the population. Other than this, climate change may impact food production itself as has been projected in a range of simulation studies for various crops (Mall et al, 2006). Changing climate may also be expected to reinforce the association between malnutrition and some infectious diseases (Caulfield et al, 2004). While malnutrition can increase susceptibility to infections by inducing alterations in hosts' immune function, infectious diseases adversely affect nutritional status by reducing an individual's capacity for food intake and nutrient absorption (Brown, 2003). Some global studies (Edirisinghe, 1986) show that deficiencies in Vitamin A, zinc, iron and other micronutrients are responsible for a substantial proportion of malaria morbidity and mortality as these nutrients are vital for building natural resistance against malarial infection. A reciprocal relationship has also been postulated between diarrhea and malnutrition in children, with diarrhea leading to nutrient loss and malnutrition predisposing diarrhea. Nutritional anemia, more common in children but nonetheless affecting people across age-groups, is already a challenge for the health situation of the state of Maharashtra.

Projected increase in frequency and intensity of extreme temperatures may also have direct impacts on human health in terms thermal stresses, such as cardio-vascular and respiratory diseases, heat exhaustion, heat cramps, dehydration and many others. An assessment of the economic implications of health impacts of climate change in Maharashtra projected that the cumulative costs for disability-adjusted life years (DALYs) lost due to diseases like malaria, diarrhea and leptospirosis over the period 2005–2050 is estimated to be around 3153 crore Indian Rupees; while mortality costs due to extreme events of flooding – every five years till 2050 – is estimated to be around 3050 crore Indian Rupees for Mumbai city alone (Kumar et al, 2008).

13.4 Projections of climate change impacts on malaria in Maharashtra

There has also been an increasing literature base investigating the influence of climate change on vector production and transmission of vector-borne diseases. Currently 2% of the total reported malarial cases in India are from Maharashtra. Presently, the transmission window (based on minimum required conditions for ensuing malaria transmission) is open for 12 months in the State of Maharashtra. In a study by Bhattacharya et al, (2006) a set of transmission windows, in terms of different temperature and humidity ranges were developed for the malarial parasite, typical to Indian conditions, by analysing the present climate trends and corresponding malaria incidences. It was observed that though the broad transmission window for malaria in terms of temperature is between 15°C and 40°C, the number of days required for a parasite to complete its life cycle varies according to the number of days a particular range of temperature persists, provided the relative humidity remains conducive. In the recent INCCA report (GoI, 2008) a district-wise map of India was generated to show the distribution of different categories of transmission windows under baseline and in A1B emission scenario of year 2030s (Figure 3). The assessment for the Western Ghats zone, which covered 6 districts of Maharashtra, showed that here the transmission windows are open for 10-12 months and continue to do so in the 2030s when transmission windows are determined on the basis of temperature only. When transmission windows are determined in combination of temperature and relative humidity, 50% of the districts under assessement show an increase in open months of transmission windows from 4-6 moths to 6-7 months. These findings are nevertheless subject to a number of uncertainties related mainly to the presence of various environmental and socio-economic factors, other than climate, which influence the transmission of the disease.

An analysis was also carried out by TERI, which tried to link climate change projections with likely distribution of those regions wherein climate may offer conditions that prove to be conducive to the development of malarial parasite in the future. Two key climate criteria (based on Bhattacharya et al, 2006) were applied to the period between May to October for each of the three time periods under analysis: Baseline (1971-2000); 2030s (2021-2040) and 2050s (2041-2060).

- **Average relative humidity varying between 55-80%**
- **Average temperature ranging between 15-35°C**

The analysis was carried out for the whole of Maharashtra. The climate criteria were first applied to the baseline period to identify the "average number of days in a year" conducive to the development of the malarial parasite (then averaged over 30 year period). In the next step, the same criteria were applied to daily weather data in the two future time periods (also averaged over 30 year periods). Then plots calculating the difference in the average number of conducive days between baseline and future time periods were generated (Figure 2 and Figure 3).

Findings from the analysis revealed that when compared to the baseline period, some regions (mostly in coastal and eastern tip of Maharashtra) show an increase in average number of conducive days (positive difference) while other regions mostly Northern, central and south-eastern Maharashtra) show varying degrees of reduction (negative difference) in both 2030s and 2050s. The negative difference (reduction in number of conducive days) is seen to be larger in 2050s than 2030s, since the projected rise in mean temperature in 2050s is high enough to exceed the specified temperature criteria for parasite development.

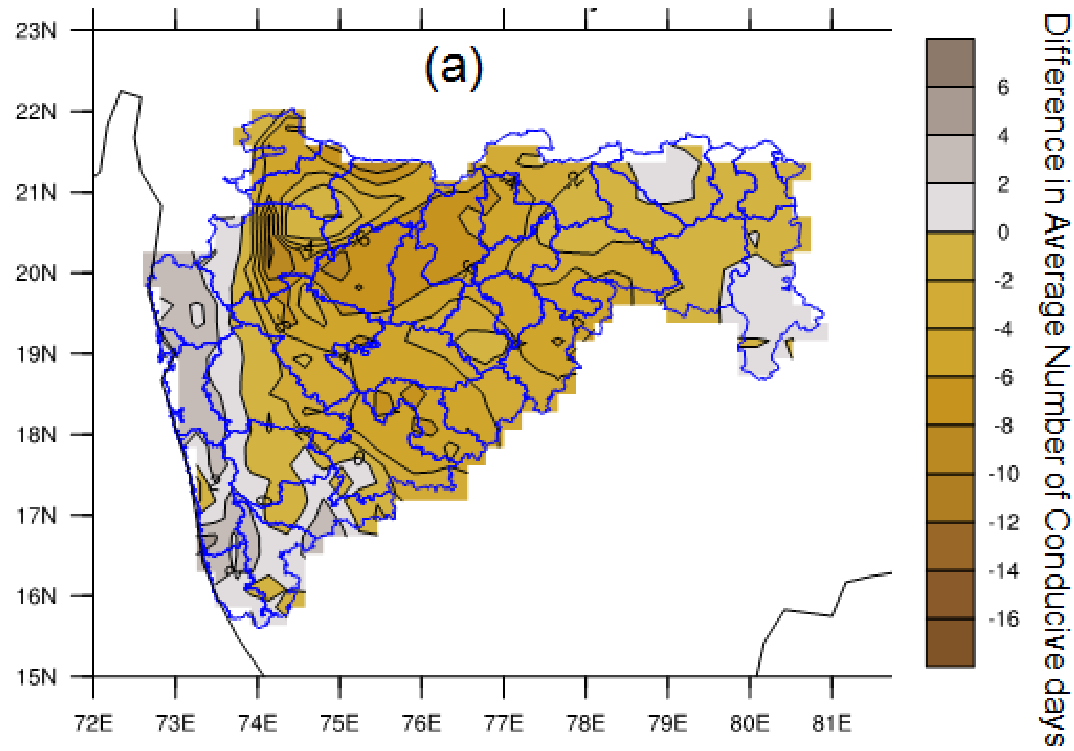


Figure 2: Plot showing Difference in the Average number of Conducive Days between 2030s and Baseline

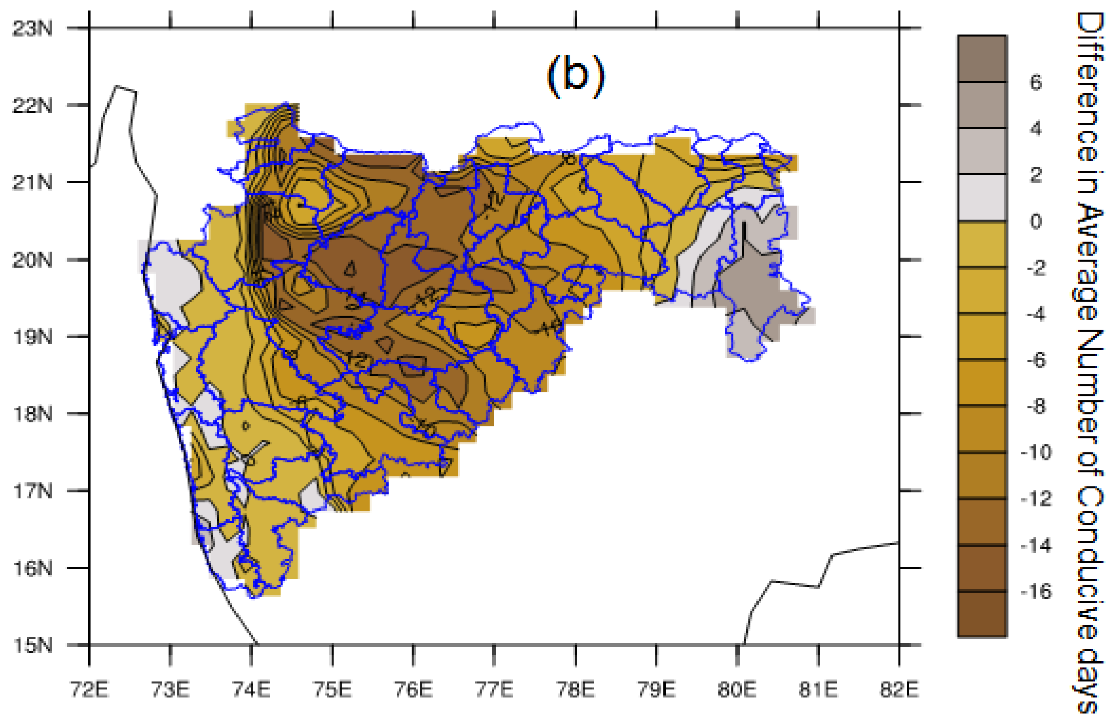


Figure 3: Plot showing Difference in the Average number of Conducive Days between 2050s and Baseline

In other words, although all parts of the State were found to be endemic, some regions (such as Eastern and Coastal Maharashtra) were found to be "more vulnerable" in the future in terms of availability of larger number of climate conducive days (i.e. days with suitable range of temperature and relative humidity). Some regions (such as central Maharashtra) showed a reduction in average number of conducive days in the future. This may indicate a positive (or beneficial) impact in terms of reduced opportunity for parasite development. Moreover, it is understood from observations that at higher temperatures, the rate of parasite development increases (Bhattacharya et al, 2006). Thus even in regions showing a reduction in average number of conducive days, a higher but suitable temperature range (as projected under climate change scenario) could mean more number of parasitic development cycles being completed within a shorter duration of conducive days.
Projected changes in temperature and rainfall are therefore bound to have an influence on the transmission of climate sensitive diseases such as malaria. However, one must acknowledge that disease transmission (especially a vector-borne disease like malaria) is a highly complex phenomenon, and is equally affected by a large number of non-climatic determinants.

13.5 Adaptation needs and priorities for the health sector

Maharashtra's health sector, though developing rapidly, is still faced with multiple challenges. High growth rates together with fast urbanization of many districts and high poverty levels are increasing the pressure on natural and socio-economic resources (including access to basic civic amenities such as clean drinking water and adequate nutrition), consequently imposing additional strain on health care services and infrastructure. Presently a large disparity can be seen in the health performance and existing health care infrastructure across different regions and population groups. Health awareness and health seeking behaviour of people is skewed, particularly in the rural regions and especially among the socially backward sections of the society. Poverty and other forms of social disadvantage translate into poorer health status of the urban poor, slum dwellers, and tribal communities who are considered as particularly vulnerable groups.

Projected changes in climate and its potential impacts may act as an additional stressor for Maharashtra's heath sector. Changes in climate parameters may increase the risk of exposure to vector, water-, and food-borne diseases, aggravate malnutrition or lead to mortality and morbidity associated with changes in intensity and/or frequency of extreme events. In particular, the projected impacts of climate change on health in Maharashtra include:

- Increase in average number of days that are conducive to malaria transmission in some regions in eastern and coastal Maharashtra in the 2030s (e.g. Thane and Raigad) and 2050s (e.g. Gadchiroli)
- Faster rate of parasite development at higher temperatures even in regions with reduction in the average number of conducive days in the 2050s (e.g. Aurangabad, Jalna, Nashik)
- Increase in human discomfort due to heat stress in parts of Konkan, Nashik, and Nagpur divisions by the 2030s, as indicated by heat index that combines air temperature and relative humidity

- Increased risk of water borne diseases due to increases in mean rainfall and proportion of extremely high rainfall events. This requires adequate drainage and hygiene
- Reduced availability of fresh water due to saltwater intrusion into groundwater aquifers near the coast

However, a number of non-climate factors such as population growth and demographic change, access to clean water, adequate nutrition and sanitation facilities, improvements in health care, and disease prevention and control programs have tremendous influence on either reducing or aggravating these climate-induced impacts.

Very few studies have been carried out in the Indian context to study the impacts that climatic changes may have on population health. However interest in this field is increasing now and more evidence is being generated. For a better understanding of the impact on different aspects of human health, it is essential to undertake focused research that can facilitate the identification of vulnerable regions and population groups and thereby aid in more informed planning and effective implementation of interventions, especially since detailed assessments in this field are currently lacking for the State. Moreover, there is a need to strengthen systems of disease surveillance and health data collection in the State, as lack of good quality and high resolution data makes it difficult to generate precise knowledge on current and changing disease patterns.

Under a future climate change scenario, expansion and improvements in water, sanitation and most importantly health care facilities, must be prioritized in regions with currently high rates of incidence of climate sensitive diseases or those with deficiencies in health care delivery. The impact of extreme events such as floods also needs to be considered while planning basic infrastructure. Planning of coastal protection measures for adaptation to hazards such as rising sea levels, fresh water depletion and cyclones therefore becomes important for safeguarding the health of coastal communities. However, for any adaptation measure to be effective it is essential that those involved in planning and implementation of adaptation strategies are made aware of the potential risk posed by climate change which can only be achieved through sustained measures for capacity building, awareness creation and practical training.

13.6 Ongoing government initiatives having implications for identified adaptation priorities

The Public Health Department of the Government of Maharashtra is making concerted efforts to ensure adequate health care services that are in line with the National Health Policy, with particular focus on rural areas especially in the tribal and backward regions of the State. Apart from the institutions of the State Government, some institutions of the Central Government (such as CGHS), private entities and non-governmental organizations are also playing important roles in meeting health care requirements in the State. Administratively, the State has been divided into eight Health Circles for facilitating planning, implementation and monitoring of health programs and schemes.

Several of the actions identified under the State Action Plans can be identified to be part of existing initiatives (in health and non-health sector), but requiring for example, an enhancement of scope, a change in direction or a renewed time plan for more effective implementation. A good example is the need to improve the quality of epidemiological data in terms of the periodicity of collection and extent of coverage. Improvements in disease surveillance and monitoring can take advantage of existing initiatives such as the Integrated Disease Surveillance Program wherein the infrastructure as well as institutional set up created for this program can be utilized more efficiently. Similarly national programs on water and sanitation, such as the Total Sanitation Campaign, the Accelerated Rural Water Supply Programme, the Accelerated Urban Water Supply Program, the National Rural Water Quality Monitoring and Surveillance Program etc. can play central roles in ensuring access to safe drinking water and healthy environments, which become a pre-requisite for building resilience of population to potential climate change risks. Moreover, since human health has critical linkages with sectors such as agriculture, water supply, sanitation, urban planning etc, it will be vital to promote coordination between various departments to facilitate a holistic approach to adaptation in the health sector. The table below presents a brief review of some key health programs and policies operational in the State that have significant consequences for population health and therefore crucially linked with climate change adaptation in the health sector.

Table 4: Some ongoing government initiative with a bearing on strategies identified under the Health Sector of the State Action Plan on Climate Change

Policy/ Program/ Scheme	Key Objectives/Goals
National Rural Health Mission (NRHM)	Reduction in Infant Mortality Rate and Maternal Mortality Ratio by at least 50% from existing levels in next seven years; Universalize access to public health services for women's health, child health, water, hygiene, sanitation and nutrition; Prevention and control of communicable and non-communicable diseases, including locally endemic diseases; Access to integrated comprehensive primary healthcare; Ensuring population stabilization, gender and demographic balance; Revitalize local health traditions and mainstream AYUSH; Promotion of healthy life styles
Reproductive and Child Health (RCH) Program-Phase II	Under the umbrella of NRHM main objectives of RCH are improving quality and outreach of RCH services and improving organizational structure and management of State Health Department
Urban RCH Programme	Improvement in the health status of the urban poor community by provision of quality integrated primary health care services
National Vector-Borne Disease Control Program (NVBDCP)	Umbrella programme for all the Vector Borne Diseases (VBDs) in the State, like Malaria, Dengue, Chikungunya, Filaria, Japanese Encephalitis
Integrated Disease Surveillance Project (IDSP)	Establish a decentralised system of disease surveillance for timely and effective public health action; and improve the efficiency of disease surveillance for use in health planning, management and evaluating control strategies
Navsanjeevani Yojana	Focuses on 15 tribal districts of the State for: Reducing IMR and MMR in the tribal area; Provision of basic health services in tribal area; Ensure safe drinking water supply to tribal area
Janani Suraksha Yojana	Increase the institutional deliveries in urban and rural areas and reduce the MMR & IMR in BPL, SC & ST families
Integrated Child Development Services	Improve the nutritional status of children in age group 0-6; lay the foundation for proper psychological, physical and social

(ICDS) Scheme	development; reduce child mortality, morbidity, malnutrition and school dropout; achieve effective co-ordination between various departments to promote child and women development; promoting child nutrition and health education amongst mothers
Integrated Management of Neonatal & Childhood Illness	Reduce infant and child mortality rates
Mobile Medical Units	Provide free of cost medical facilities to rural masses in remote areas
Total Sanitation Campaign	Improving the general quality of life in the rural areas; accelerating sanitation coverage in rural areas; generating felt need through awareness creation and health education; covering schools in rural areas with sanitation facilities; encouraging suitable cost effective and appropriate technologies; bringing about a reduction in the incidence of water and sanitation related diseases

13.7 Key recommendations

In the light of projected changes in climate, future trends in socio-economic scenarios, existing vulnerabilities in the health sector and consequent potential risks to human health, the following priorities are identified for the health sector of Maharashtra:

- Strengthen system of disease surveillance and health data collection in the State, as lack of good quality and high resolution data makes it difficult to generate precise knowledge on current and changing disease incidence rates. Enhance monitoring & community surveillance for climate-sensitive diseases and develop health-related climate services and early warning systems.
- Improve monitoring and adequate training to health sector staff on potential risks posed by climate change.
- Invest in research related to climate change and health. Focus on different "climate-sensitive" health impacts, based on understanding of region specific risks, thereby calling for increased research activities in this field

13.8 Action plan

- Develop early warning tools in collaboration with meteorological agencies for different end-users, e.g. early warning system for heat waves for urban centres such as Mumbai, for fishermen, for farming communities, and provide community climate services and health advisories.
- Develop and maintain a digital health database (e.g. cases reported daily, mortality, morbidity) at fine spatial and temporal scales for climate-sensitive diseases, including vector-borne diseases, water borne diseases, heat stress, and nutrition related disorders. Prioritize districts with a concentration of tribal populations such as Dhule, Nandurbar, Chandrapur, Gadchiroli, Bhandara, and Gondia.
- Promote community surveillance programmes and awareness programmes (e.g. for management of stagnant water). Expand community surveillance programme piloted under the Tribal Action Plan in Taloda and Akkalkuwa blocks of Nandurbar district to cover all other vulnerable districts.
- Study the regional pattern of climate-sensitive diseases and disease outbreaks (including malaria, dengue, chikungunya, diarrhea, and cholera) to identify

changing trends and trigger events, and provide regular feedback to state surveillance units.

- Introduce norms for working hours for labourers to reduce their direct exposure to heat and construct shelters near farm areas, particularly in districts where temperature increase is projected to be high, such as in Nagpur division.
- Increase investment in health research on identification of linkages between temperature and rainfall increase and incidence of vector borne diseases, and on mutations and emergence of new diseases due to changes in temperatures and humidity patterns.
- Introduce additional training module on climate change risks and impacts for health sector staff; to be imparted by the State Public Health Institute.

13.8.1 Adaptation Action: Enhanced monitoring and surveillance for climate-sensitive diseases

Action category: Technology deployment-capacity building; State wide; short term and continued in the long term; Rural and urban

Rationale: There is need to strengthen systems of disease surveillance and health data collection in the State, as lack of good quality and high resolution data makes it difficult to generate precise knowledge on current and changing disease patterns. Improved monitoring can also allow for better prevention and control of health risks from changing climate by shortening response time in case any changes are detected in disease patterns

Key components of the action:

- Develop and maintain a decentralized digital health database at fine spatial and temporal scales specifically for climate-sensitive diseases (vector-borne diseases, water borne diseases, heat stress, nutrition related disorders, direct and indirect health effects from extreme events like injury, death, psychological health problems etc). Districts with a concentration of tribal populations can be prioritized; such as Dhule, Nandurbar, Chandrapur, Gadchiroli, Bhandara, Gondiya etc.
- Undertake regular analysis of data at district and sub-district level to identify any changing trends (spatial and temporal) in diseases and providing regular feedback to state surveillance units
- Develop early warning tools in collaboration with meteorological agencies with different end-users in mind (Early warning system for heat waves can be developed for urban centers such as Mumbai)
- Expand program of community surveillance which is being piloted as part of the Tribal Action Plan in Taloda and Akkalkowa blocks of Nandurbar district so as to cover all other districts

Expected outcomes: Creating a digital health database with an improvement in quality of data, periodicity of collection and extent of coverage

Implementation:

- **Timeframe:** 1 years for conducting a gap assessment to identify districts/blocks with deficiencies in existing surveillance system; next 3 years for developing adequate infrastructure and capacity; followed by long term surveillance
- **Links with ongoing government initiatives:** Infrastructure, institutions and human resources established for current systems of surveillance can be utilized and improvised to specifically address climate related risks. Link with existing systems of surveillance such as Integrated Disease Surveillance Program, National Vector Borne Disease Control Program.
- **Nodal Govt. Department:** State Public Health Department as the nodal agency with support from the State Bureau of Health Intelligence & Vital Statistics. As well as Mobilizing private health centers/hospitals to contribute to surveillance database
- **Specific capacity needs:** Adequate infrastructure provision such as computer hardware and software, internet connectivity and human resources, especially in surveillance units at lower scales (such as at Block level) and in under-developed tribal areas; Training to staff handling the information flow including data managers, data entry operators, epidemiologists, microbiologists, health workers etc.
- **Financial needs**: Donors such as The World Bank who have previously funded diseases surveillance programs in the country can be approached for funding. Estimated cost of implementation: INR 2.5 crore for initial set up of hardware and software, followed by 85 lakh/year (for all districts).

13.8.2 Adaptation Action: Research-based prioritization of regions and population groups for targeted interventions to address health risks from climate change

Action category: Research & development; State-wide and Region-specific; Short term

Rationale: For a better understanding of the impact on different aspects of human health, it is essential to undertake focused research that can facilitate the identification of vulnerable regions and population groups and thereby aid in more informed planning and effective implementation of interventions, especially since detailed assessments in this field are currently lacking for the State.

Key components of the action:

- Identify data needs (and existing gaps) for undertaking assessments on the impact of climate change on various dimensions of human health
- Study the regional pattern of different climate-sensitive diseases and disease outbreaks (such as malaria, dengue, chikungunya, diarrhea, cholera, heat stress etc.) by undertaking regular analysis of data, at district and sub-district level, to identify changing trends and providing regular feedback to state surveillance units. This can also include identification of trigger events (climatic and non-climatic factors) that influence

the infection-transmission-spread of climate sensitive diseases. The data generated from Adaptation Action 1 (described above) can directly feed into this field of research.

- Procure/develop/customize health impact models to assess potential impact and validate predictive modeling results with qualitative & quantitative assessments
- Promote coordination between various departments to facilitate interdisciplinary research since human health has critical linkages with sectors such as agriculture, water supply, sanitation, urban planning etc.

Expected outcomes: High quality research outputs (specifically for the State) that help generate evidence on the most significant impacts and most vulnerable groups and thereby help to prioritize areas for interventions

Implementation:

- **Timeframe:** 5-7 years
- **Links with ongoing govt. initiatives:** Research activities can be linked to ongoing programs such as the Integrated Disease Surveillance Project and National Vector-Borne Disease Control Program which are actively collecting data on various diseases and also undertaking trend analysis for certain diseases.
- **Nodal Govt. Department and cross-department association:** State Public Health Department with support from state universities (for example Maharashtra University of Health Sciences, Nashik), public health laboratories, medical colleges, meteorological department and other research organizations within and outside the State.
- **Specific capacity needs:** Scientific/technical training of health sector staff for example, the epidemiologists, to carry out research in vulnerability and impact assessments by facilitating hands on training in the use of retrospective as well as prospective models and use of software including GIS tools for spatial analysis
- **Financial Needs:** A research program specifically on climate change and health can be launched seeking support under the National Mission on Strategic Knowledge on Climate Change. ICMR, which is the nodal agency for medical research can be another potential source of research funding.

  Estimated cost of implementation: INR 3 Crore

13.8.3 Adaptation Action: Adequate training to health sector staff to increase awareness on and response capacity to potential impacts on human health

Action category: Training and capacity building; State wide; short term and continued in the long term; specifically for health sector staff

Rationale: For any adaptation measure to be effective it is essential that those involved in planning and implementation of adaptation strategies are made aware of the potential risk posed by climate change which can only be achieved through sustained measures for capacity building, awareness creation and practical training. This becomes all the more essential as the domain of "climate change and human health" is relatively new and scientific understanding is still limited.

Key components of the action:

- Conduct a Training Needs Assessment (TNA) specific to different tiers of health sector staff including physicians, data managers, data entry operators, epidemiologists, microbiologist, laboratory staff and community level health workers etc.
- Facilitate scientific/technical training to epidemiologists, to carry out research in health impact assessments by facilitating hands on training in the use of retrospective and predictive techniques, models and software as well as RS and GIS tools for spatial analysis
- Introduce additional training module on climate change risks and impacts; imparted by the State Public Health Institute
- Include climate concerns in curriculum of medical and nursing students
- Taking up region specific IEC activities involving PRIs, Co-operatives, Women Groups, Self Help Groups, ASHA workers and local NGOs

Expected outcomes: Enhanced awareness among health sector staff on how climate change can affect human health and potential response strategies

Implementation

- **Timeframe:** 1 year to conduct Training Needs Assessment, followed by 1 year to prepare material for training and awareness creation, followed by regular and periodic training and awareness creation programs (long term).
- **Links with ongoing govt. initiatives:** Can be linked to existing training programs under the National Rural Health Mission
- **Nodal Govt. Department and cross-department association:** Public Health Department as the nodal agency with support from institutes such as Public Health Institute (PHI) in Nagpur, which is identified as the apex training institute for health in Maharashtra (with a number of District Training Centers, Hospital Training Centers and Block Training Centers). Also Health and Family Welfare Training Centers can facilitate the training of trainers and development of training modules for overall capacity building of health department officials on climate change issues.
- **Specific capacity needs:** Sensitize policy makers, on health risks of climate change and the need for mainstreaming adaptation responses, through IEC activities such as seminars, workshops, trainings, dissemination of related scientific literature
- **Source of funding:** National Rural Health Mission can be a potential source of funding for training related activities. Estimated cost of implementation: 70 Lakhs/year

14. Extreme rainfall, flooding, and adaptation in Mumbai Metropolitan Region (MMR)

14.1 Vulnerability of Mumbai to urban flooding

The Mumbai Metropolitan Region (MMR) area of 149 km² in 1971 increased to 1000 km² by 2010. Its forest area declined from 1045 km² to 879 km² over the same period. Similarly, area under industry increased from 45 km² to 140 km², while agriculture area reduced from 2098 km² to1381 km². MMR is the fourth largest urban agglomeration in the world with a population of 12.5 million (2011). The daily consumption of power is 2750 MW and an estimated 101155 tons per day of municipal solid waste is generated.

MMR completely depends on locally stored rainfall (impounded by building of reservoirs in Thane, Raigad and Nashik districts) for its drinking and industrial water supplies. These reservoirs are recharged through the heavy rains received during the months June-October. Water resource development plan of MMR essentially focuses on impounding more of the rain water through building of new reservoirs and as many as 12 new reservoirs are planned (Regional plan of MMR). However, scant attention is paid to increasing the infiltration of rain water which can not only improve the water quality and storage capacity of the reservoirs but also improve the dry season flows and the ground water level. Much of the rain water still flows down the sea. Hence, adaptive strategies essentially need to focus on increasing infiltration of the rain water.

It is pertinent to point out that the capacity of forests and grasslands in the MMR to deliver such hydrological services is enormously reduced by grazing and other biotic pressures. Hence, protecting forests around water catchment areas is no longer a luxury but a necessity. Further, forest management practices, mix of tree species and ages and the forest structure can also impact water quality and yield. Hence, it is important to integrate water development and water treatment planning with forest management as well as ease the biotic pressure on the forests and the grasslands.

The geographical condition makes Mumbai susceptible for heavy rainfall. Impact of anthropogenic activities i.e. unsustainable use of resources, reclamation of low lying areas, climate change and global warming, antiquated drainage system and chocked sewers, uncontrolled and unplanned development of the city especially in Northern suburbs, destruction of mangrove and natural ecosystem because of the encroachment by the builders and irresponsible city dwellers, violation of Coastal Regulation Zone (CRZ) rule, loss of wetlands, lack of disaster management plan and no clear coordination between several agencies responsible for city development and planning.

The entire storm water outflow system of Mumbai has been so far based purely on gravity. There are closed drains in the old island city (Colaba to Mahim) and open drains or nallas in suburbs. (Chitale, 2006). They both discharge by gravity either in the creek arms or in to the open sea along the east and west coasts of Mumbai. The low lying portions of the island city have a history of getting regularly flooded up to 5-6 times a year, generally for a few hours every time, when high intensity rainfall is coupled with high tide in the sea. There is water logging in the central Mumbai belt under such conditions. At many locations, land levels are below the high tide level e.g. Sat Rasta, Lower Parel, Grant Road, etc. The mean sea level of Mumbai is very close to the Indian Mean Sea level at 0.01 m. The average high tide level is 2.5 m, the annual highest peak tide level being 2.75 m. The average low tide level is (-) 2.0 m (i.e. two meters below the mean sea level). It is the low tide periods (about 10 to 12 hrs in a day below the mean sea level) that have been providing relief during the storm by draining out the accumulated surface waters. The level of a large coastal belt in Mumbai is close to 3.00 M e.g. Juhu aerodrome; and Khar. These are the vulnerable areas for congestions and submergence by tide and flood interacting. Ground levels in many low lying areas in Island city & suburbs are just 2.25 to 3 meters above MSL, while the flood levels in the creeks also have the same heights.

Mumbai is prone to flooding and witnesses severe disruptions almost annually; for example, between 2004 and 2007, Mumbai experienced flooding each summer. But in July 2005, the city experienced the worst flooding in its recorded history, resulting in huge damages and around 500 fatalities (GoM, 2005). The present storm-water drainage system in Mumbai was put in place in the early 20th century and was capable of carrying only 25 mm of water per hour which was extremely inadequate on a day when 944 mm of rain fell in the city. The model-based assessment carried out under the present study suggests that even after augmentation of the drainage capacity to 50 mm/hour, Mumbai's low lying areas need special attention as these areas are exposed to the risk of high flood level and that flood risk mitigation practices should be implemented for the city.

14.2 Methodology for modelling assessment

The objective of the modelling assessment is to generate flood risk maps of Mumbai for estimation of the areas which are likely to be flooded in the case of extreme rainfall events. These modelling results and flood risk maps can be used for flood forecasting, flood risk mitigation and disaster management.

The hydrodynamic model in the MIKE 21 Flow Model (MIKE 21 HD) is a general numerical modelling system for the simulation of water levels and flows in estuaries, bays and coastal areas. It simulates unsteady two dimensional flows in one layer (vertically homogeneous) fluids and has been applied in a large number of studies. The model is based on the very basic mass balance equation and conservation of momentum equation. These two equations together, describe the flow and water level variations. These equations are in the form of Saint Venant equation used in MIKE 21. (DHI, 2011).

Five different rainfall intensities, duration and frequency are selected in this modelling approach shown in the table **VI** 6 DHI MIKE21 was used to simulate these rainfall events. The rainfall Data for 25-26 July 2005 was obtained from IMD Mumbai for Santa cruse rain-gauge station of 1 hr frequency and other rainfall data was collected from BMC for Andheri rain gauge station at 15 minute frequency. ASTER DEM was used for the surface elevation with spatial resolution of 30m. The topographic data was first converted in ArcGIS to ASCII file that could be used in MIKE 21. A simulation in MIKE21 was used to determine the resulting water level and flood velocity during this event.

Table 1 Rainfall Events Selected for Flood Modelling

Events	Total Rainfall (mm)	Total Duration
✵26-07-2005	944.42	24 Hrs
30-06-2007	314.45	18 Hrs 30 min
24-06-2013	66.04	3 Hrs 30 min

✵ Extreme Event of 2005, highest rainfall event ever recorded over Mumbai

14.2.1 Data collection

14.2.1.1 Rainfall Data

The rainfall data of Mumbai city measured at Santacruz, Colaba and Dahanu weather stations for the event 26-27 July 2005 is provided by the IMD Mumbai.

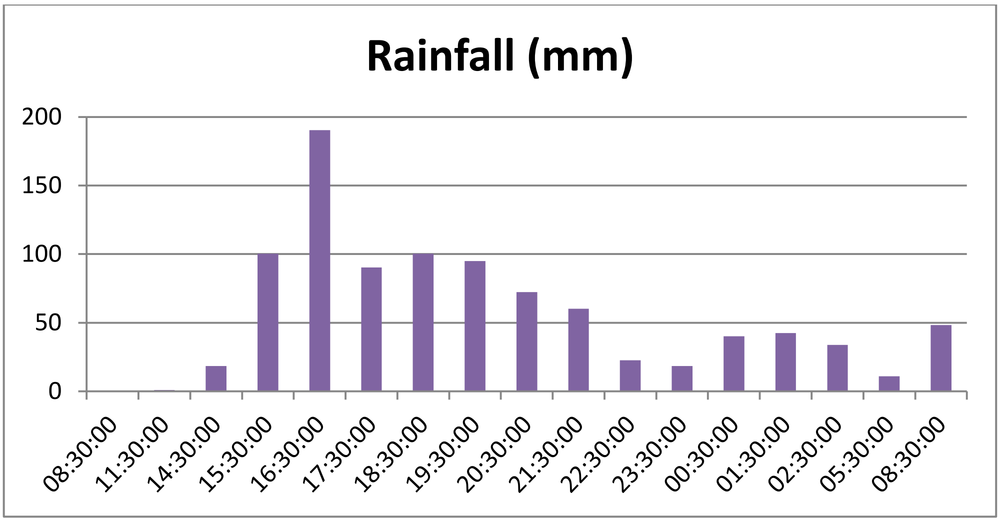
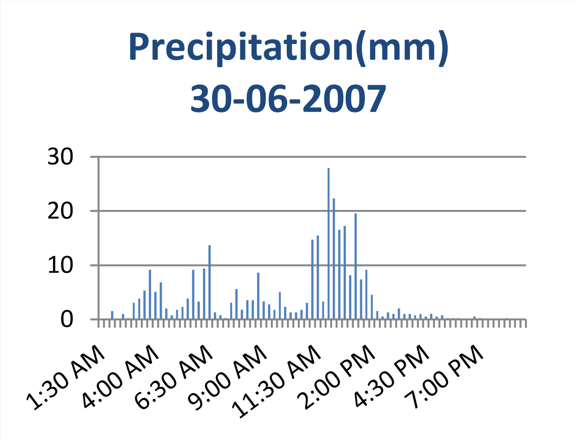


Fig 1. Rainfall Data (Santacruz) started 26 July 08:30 IST and ended on 27 July 08:30 IST, 2005

For the estimation of flooding, fine time resolution rainfall data was used. Hourly data was available only for Santacruz station between 26th July 2005, 14:30 IST to 27th July 2005, 02:30 IST. 15 minute rainfall data for other than 26-27 July is collected from BMC AWS. These rainfall data was converted into time series data in .dfs0 format in MIKE ZERO toolbox and added in the model.



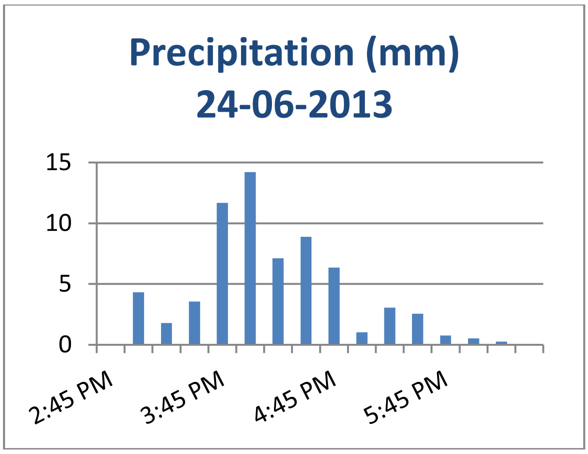


Fig 2. Selected Rainfall events for different Intensity, Duration and Volume

14.2.1.2 Elevation Data

The study area is entire Mumbai metropolis and has coordinates between 72.73^0 longitudes to18.84^0 latitude. The topographic data was in the form of DEM (Fig. 3). For the land ASTER global DEM is used for elevation and for the Sea bathymetry Global Bathymetry data is used. First the shape file for the land and sea within the study area was delineated in ArcGIS and clipped to extract data from the corresponding shape files. Both these file was then added to make it one DEM for the study (Fig 3). This data file cannot be used in MIKE 21 for construction of bathymetry. This DEM file is converted into ASCII text file. All no data values and unrealistic elevation of zero meters in land has been deleted. Interpolation tool is used for assigning values to those points.

14.2.1.3 Wind Data

Wind data was obtained from the Weather Research and Forecasting (WRF) Model, published in 2010 for Mumbai rainfall. The wind condition is considered as a constant value in time and space. From the WRF model the value of wind speed was 15 m/s in 254^0 directions for 2005 events. For other events wind data is collected from the BMC AWS at 15 minute time series format. Evaporation from the surface is considered 5 mm/day for this model. The evaporation data was obtained from the monthly evaporation map prepared for the entire India by IMD. Drainage capacity of the city is taken as 25 mm/hour (Chitale, 2006). Tide data which is an important hydrodynamic parameter for this study is sited from the online data source for Arabian Sea which is recorded on daily basis near Mumbai station.

Other details of setting up the model are provided as Annexures.

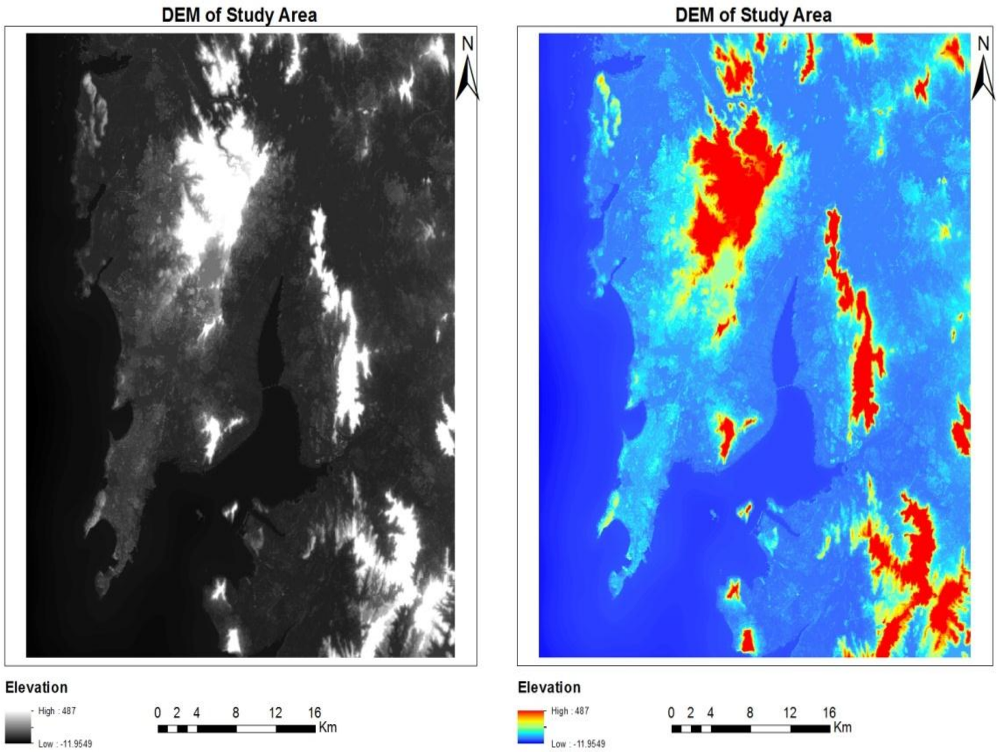


Fig 2. DEM of the study Area in ArcGIS 10

14.3 Results

14.3.1 Extreme rainfall event of 2005 (with drainage capacity of 25 mm/hr rainfall Intensity)

The model is simulated considering two scenarios first one is with the capacity of 25 mm/hr rainfall intensity of Drainage and second considering capacity of 50 mm/hr rainfall intensity of drainage including tidal variation. Flood maps were generated for different time steps and time series manner and one for the maximum water level map at the end of the simulation has been analyzed for these events. Here Drainage means manmade storm water drainage system, as the model is considering the Natural drainage according to the topography and gradients.

Flood level is distributed as per the US-EPA (United States Environmental Protection agency) flood stage definition. Flood stage is an established gage height for a given location above which a rise in water surface level begins to create a hazard to lives, property, or commerce. On this basis flood stage is classified into 3 subclasses.

1. **Minor Flooding** is defined to have minimal or no property damage, but possibly some public threat (water level between 0.05m to 0.5m)
2. **Moderate Flooding** is defined to have some inundation of structures and roads in low lying areas. Some evacuations of people and/or transfer of property to higher elevations may be necessary (water level between 0.5m to 1m)

3. **Major Flooding** is defined to have extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations are necessary. (Water level 1m and above)

Grid points which has water level below 0.05 m is not considered as flooding points and analysed as no flooding category in the model results.

Rainfall started at 14:30 IST and the get highest intensity at 18:30 IST with 190.3 mm/hr. at 21:30 IST the water level rises above 3.5m in Low lying areas. Nearly 47.6% area has the water depth upto 0.5m and 3.7 % area has the water level between 3 m and above. Areas of Panvel Creaks, Mahim Creaks, Malad West and Bandra West have water level upto the 3 meter and on some grid points more than 3.5m. Especially the low lying areas near the creaks are severely affected. In the flood map it has been observed that the low lying areas need to have maximum attention. In case of flooding it was found in studies that a single story building would be damaged by 0.5 m flood with velocity of 4 m/s while if the flood velocity is 0 m/s the building would be damaged if the water level is above 3 m (Kreibich, 2009). However in the built-up areas water level increases because of the impervious strata and poor drainage system and it is a major cause of concern for the flood management practices and related damages in urban landscape.

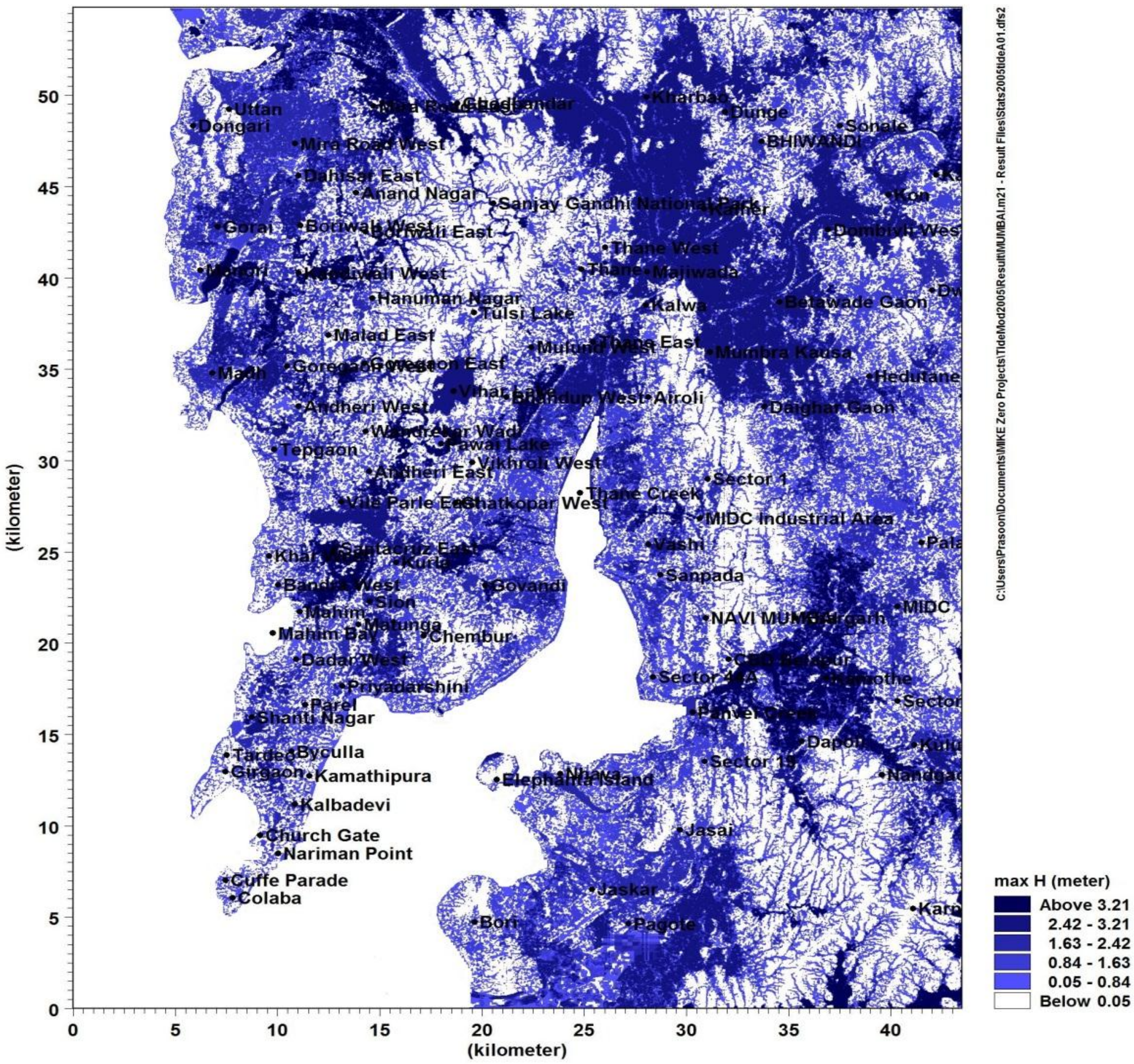


Fig 4 Water Depth Map 2005 with tide variation and 25 mm/hr drainage

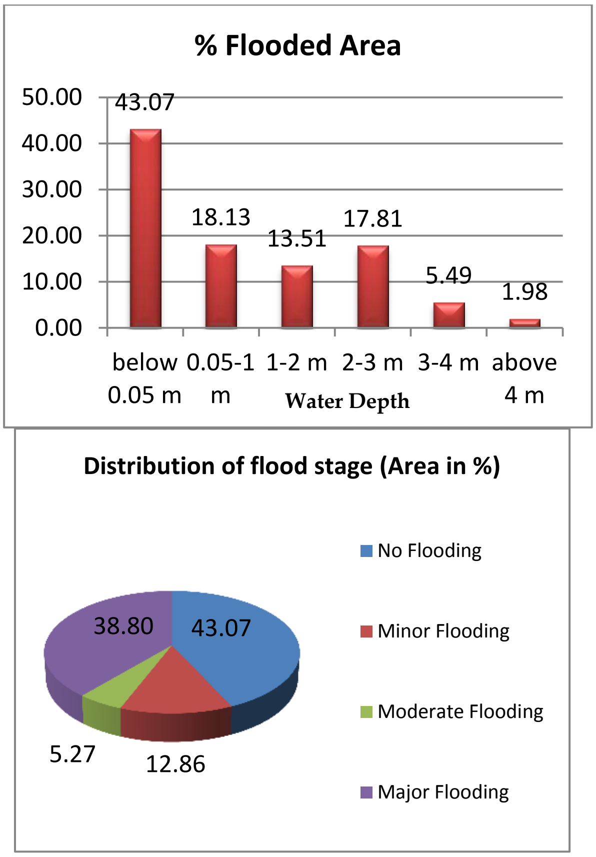


Fig 5 Water Depth distribution Chart 2005 (25 mm/hr rainfall intensity Drainage)

Flood level and stage are affected by the rainfall intensity, duration and with high tide level resulting in grievous flooding in Mumbai and the storm water drainage capacity is not capable to accommodate this kind of rainfall intensity and volume. The reason is at the peak intensity of rainfall there is High tide and the drainage system is not capable of to evacuate water into the sea. However when there are low tide level drainage work properly and the flood level get reduced. In conclusion we can say in the presence of high tide water get accumulated as the drains are inappropriate to drain out storm water and if the drainage works properly combined with low tide the city will experience comparatively less inundation even in the very heavy rainfall. Same conclusions can be made from the flood maps of 2013 rainfall, although the rainfall is not that much high and not happened for long duration but we can observed localized flooding in some parts but the impact of such rainfall is not alarming. In recent years the drainage capacity for Greater Mumbai has been increased to drain out 50 mm per hour rainfall intensity as recommended by BRIMSTOWAD. Considering the up-gradation of drainage the model is simulated including 50 mm per hour rainfall drainage capacity for 2005 rainfall event. It is observed that though the flood level has decreased in several areas as compare to previous 25 mm/hr rainfall intensity drainage, the flood is unavoidable and it has almost same geographical area coverage as it was previously. But with the decrease in intensity of rainfall with time the flooding level and duration of flood get reduced as compare to previous drainage system.

For 2007 rainfall event the total volume of rainfall was 318 mm in 18 hours. We can consider this rainfall as High Intensity with long duration rainfall event. Mumbai receives this amount of rainfall almost every year. The model was simulated using this amount of rainfall for the year 2007 with all other data mentioned above in data requirement section. Though the 26th July 2005 event was extreme as compare to 2007 rainfall, but coincide with high tide almost 40 % of the Mumbai city was affected with high and moderate flooding.

14.3.2 Extreme rainfall event of 2005 (With drainage capacity of 50 mm/ hr rainfall Intensity)

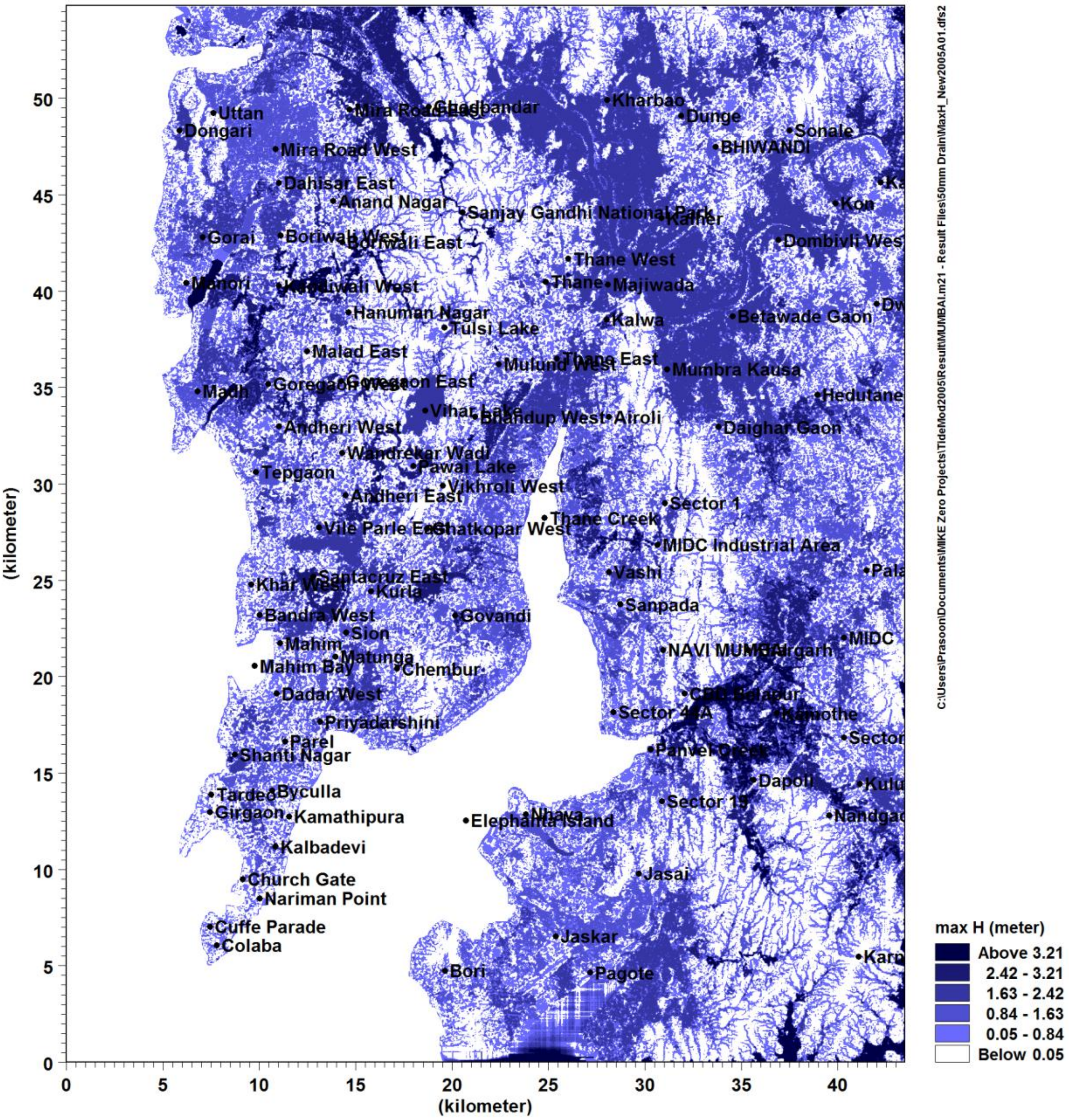
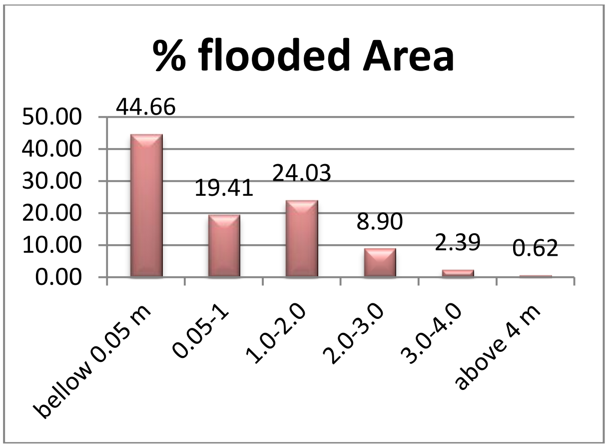


Fig 6 Water Depth Map 2005 with tide variation and 50 mm/hr drainage



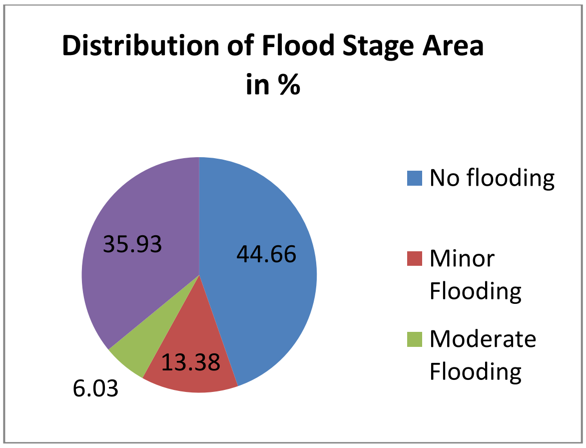


Fig 7 Water Depth distribution Chart 2007 (With tide Variation and 50 mm/ hr Drainage)

14.3.3 Rainfall Event of 2007

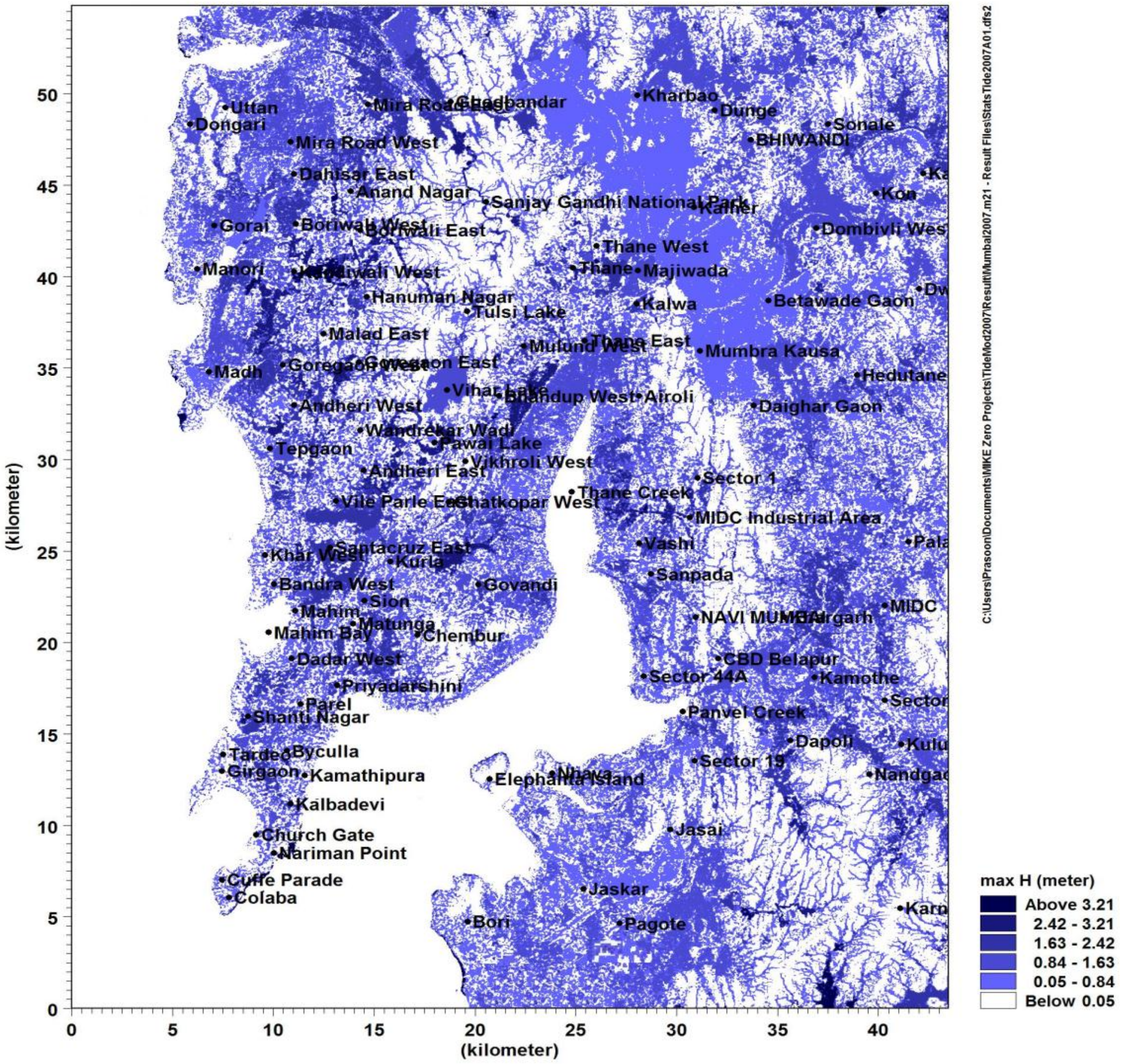


Fig 83 Water Depth Map 2007 with tide variation and drainage

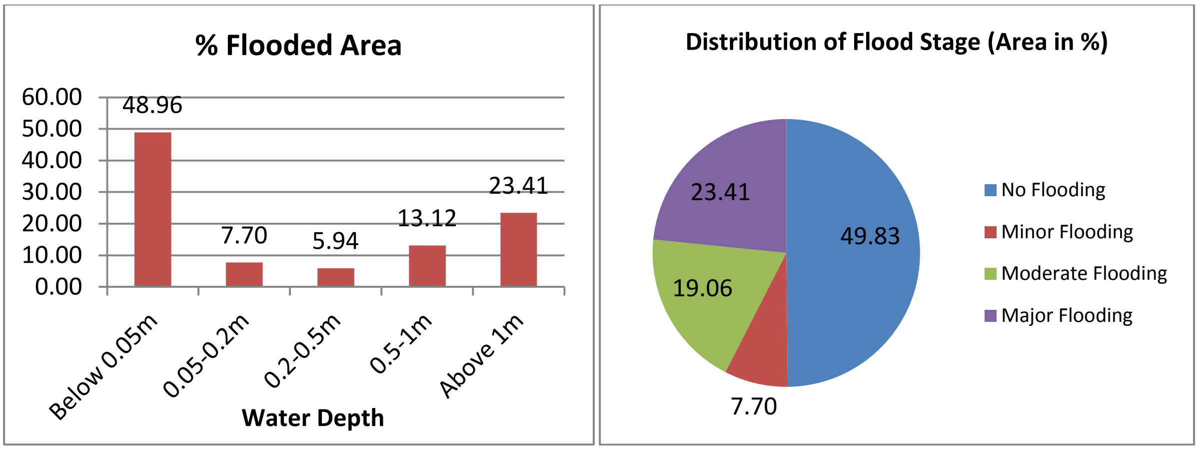


Fig 9 Water Depth distribution Chart 2007 (With tide Variation and Drainage)

14.3.4 Rainfall Event of 2013

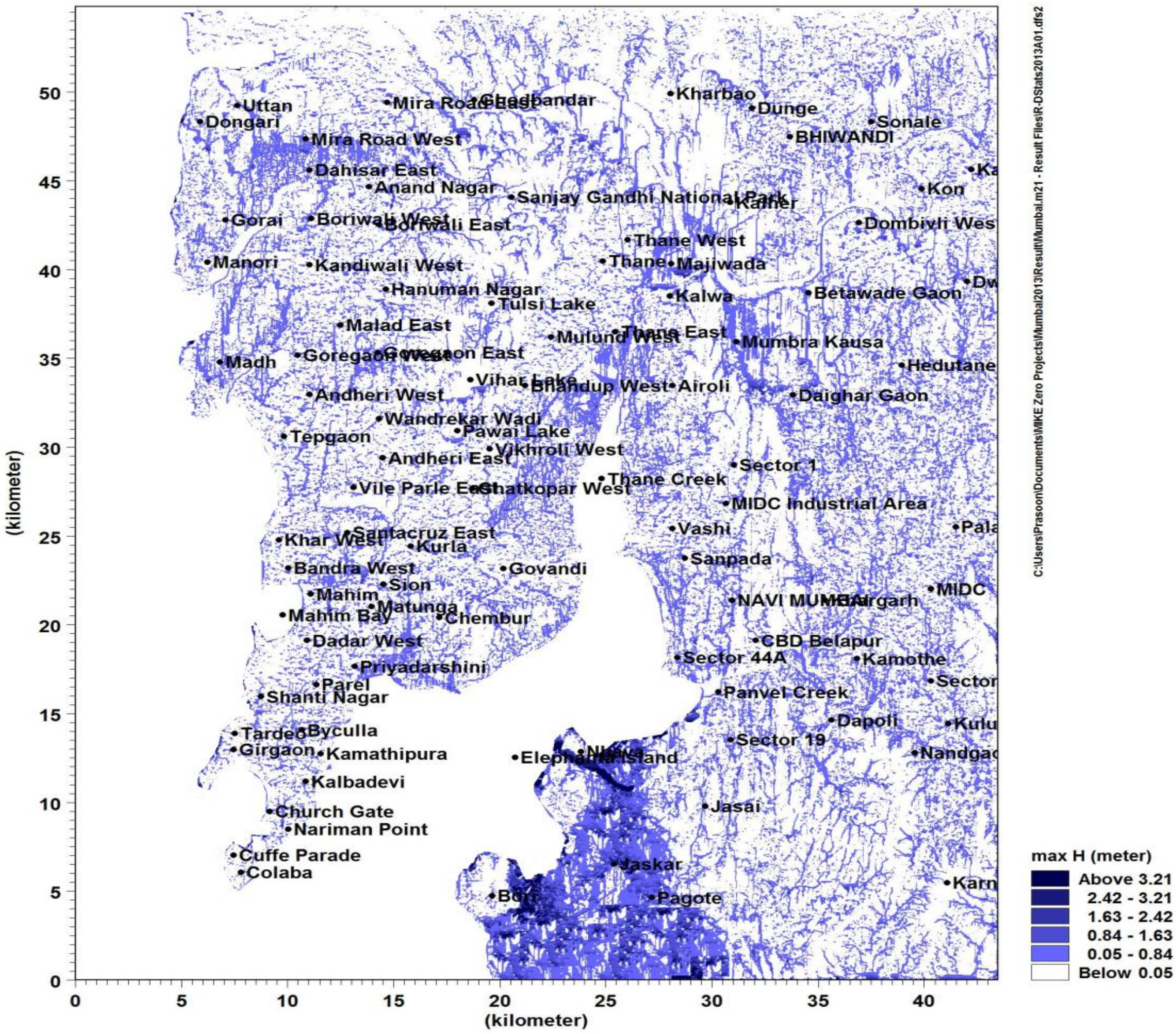


Fig 10 Water Depth Map 2013 with tide variation and drainage

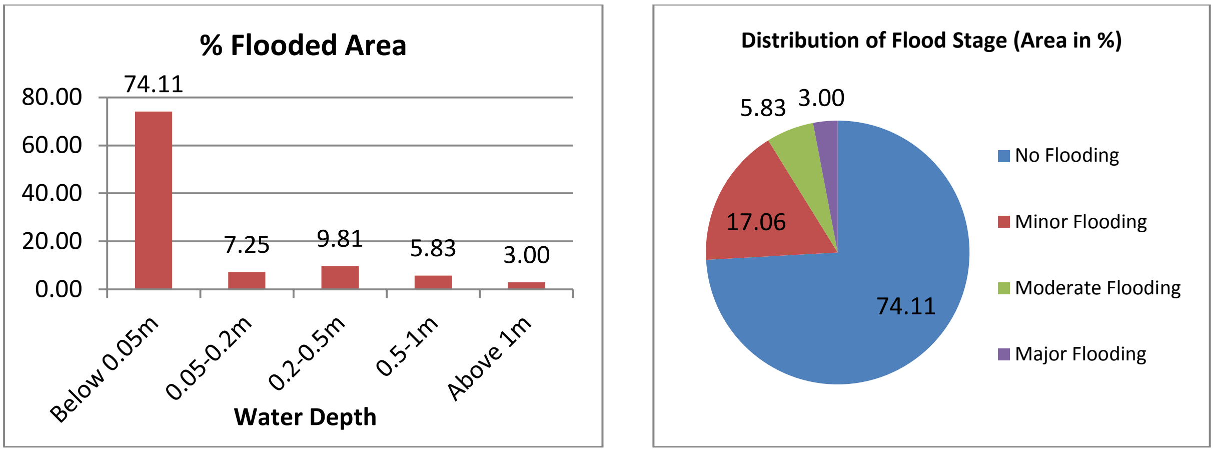


Fig 114 Water Depth distribution Chart 2013 (With tide Variation and Drainage)

14.3.5 Validation

Validation of the flood risk map is based on **Accuracy analysis** *i.e.* the modeled v/s observed value. Observed flooded points and flood level in Mumbai for 26th July 2005 rainfall event are taken from the **Greater Mumbai Disaster management action plan report Volume 1 and Fact Finding Committee report Volume 2**. Flood points were taken from the report across the Mumbai for the validation which includes slums, roads, junction, subways, railway stations and proper settlements and were compared with the modeled flood level and Location. The model results show close association with observed data points.

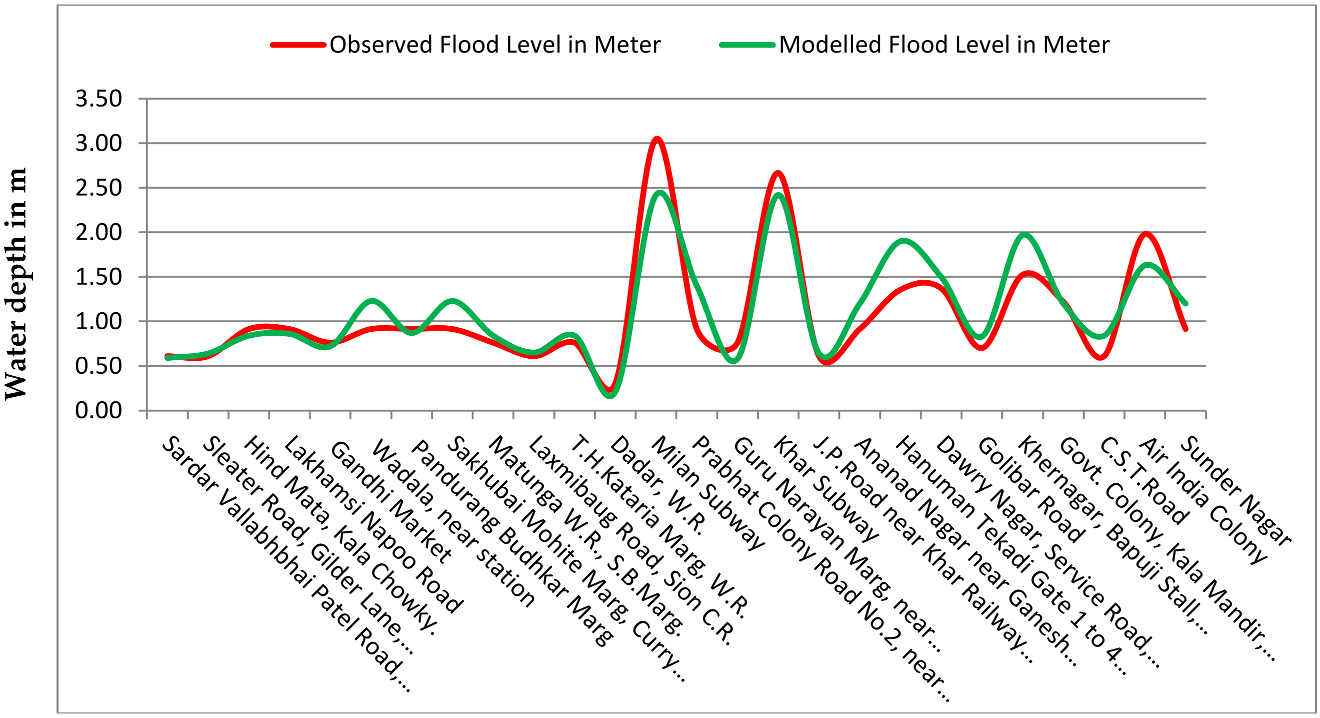
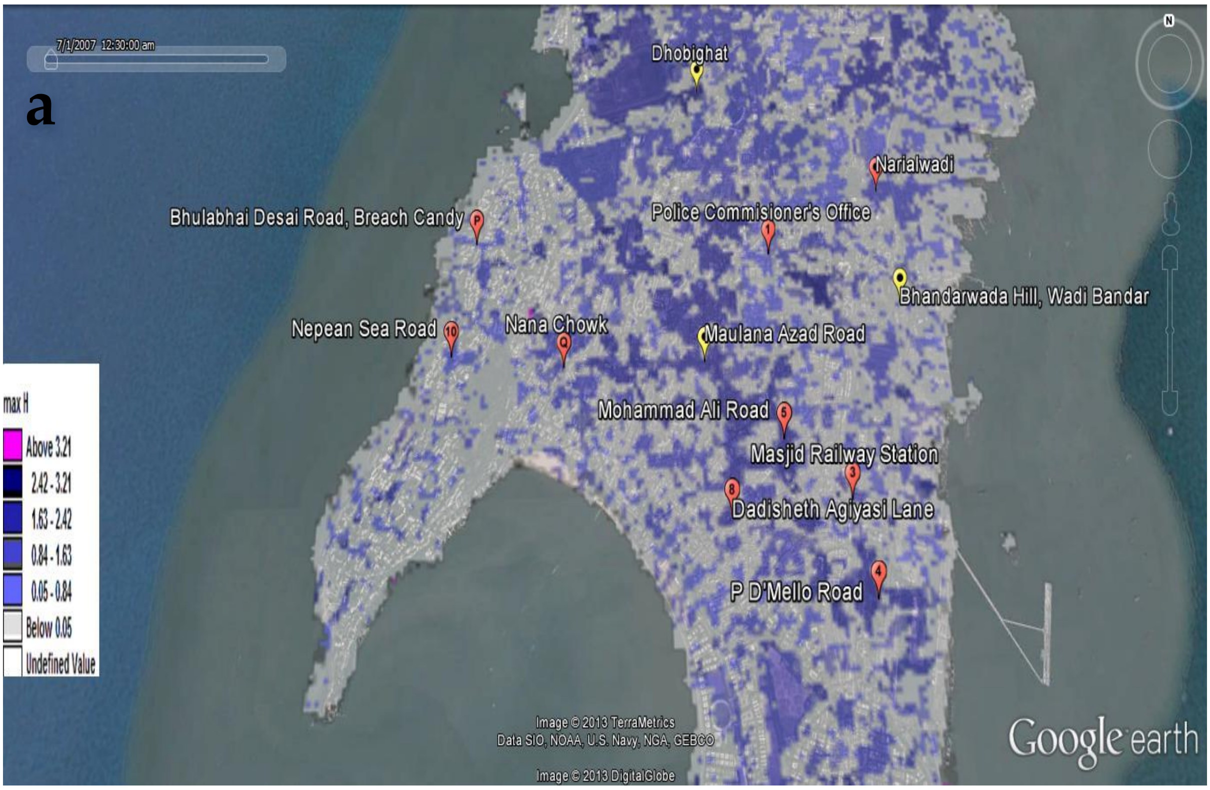


Figure 12 Validation: Modelled v/s Observed Flood Level

Ward	Number of slums which get affected	Number of flooding points
1. A	9	16
2. B	Nil	5
3. C	Nil	6
4. D	5	13
5. E	12	7
6. F/South	13	4
7. F/North	Nil	10
8. G/South	3	6
9. G/North	5	6
10. H/East	7	20
11. H/West	8	5
12. K/East	Nil	Nil
13. K/West	10	10
14. L	12	11
15. M/East	3	2
16. M/West	6	7
17. N	3	13
18. P/South	4	32
19. P/North	6	29
20. R/South	7	8
21. R/North	15	5
22. S	3	12
23. T	4	8

Areas
Church gate, Nariman Point, cuffe parade,Colaba
Fort
Mumbadevi, gymkhana,
Malabar Hill,
Kamathipura, Railway colony
Parel
Sion
Worli, Shanti Nagar
Mahim, Dadar Railway Station, Matunga
Santacruz
Bandra West, Khar West
Andheri East
Andheri West, Ville Parle West, Juhu, Versova
Kurla West
Chembur, Trrombay
Shastri Nagar
Ghatkoper, Vikhroli
Goregaon
Malad, Kandiwali East
kandiwali West, Boriwali
Dahisar, Boriwali
Bahandup
Mulund

Fig 135 Ward wise list of Observed Flooded points in Mumbai according to Greater Mumbai Disaster management action plan



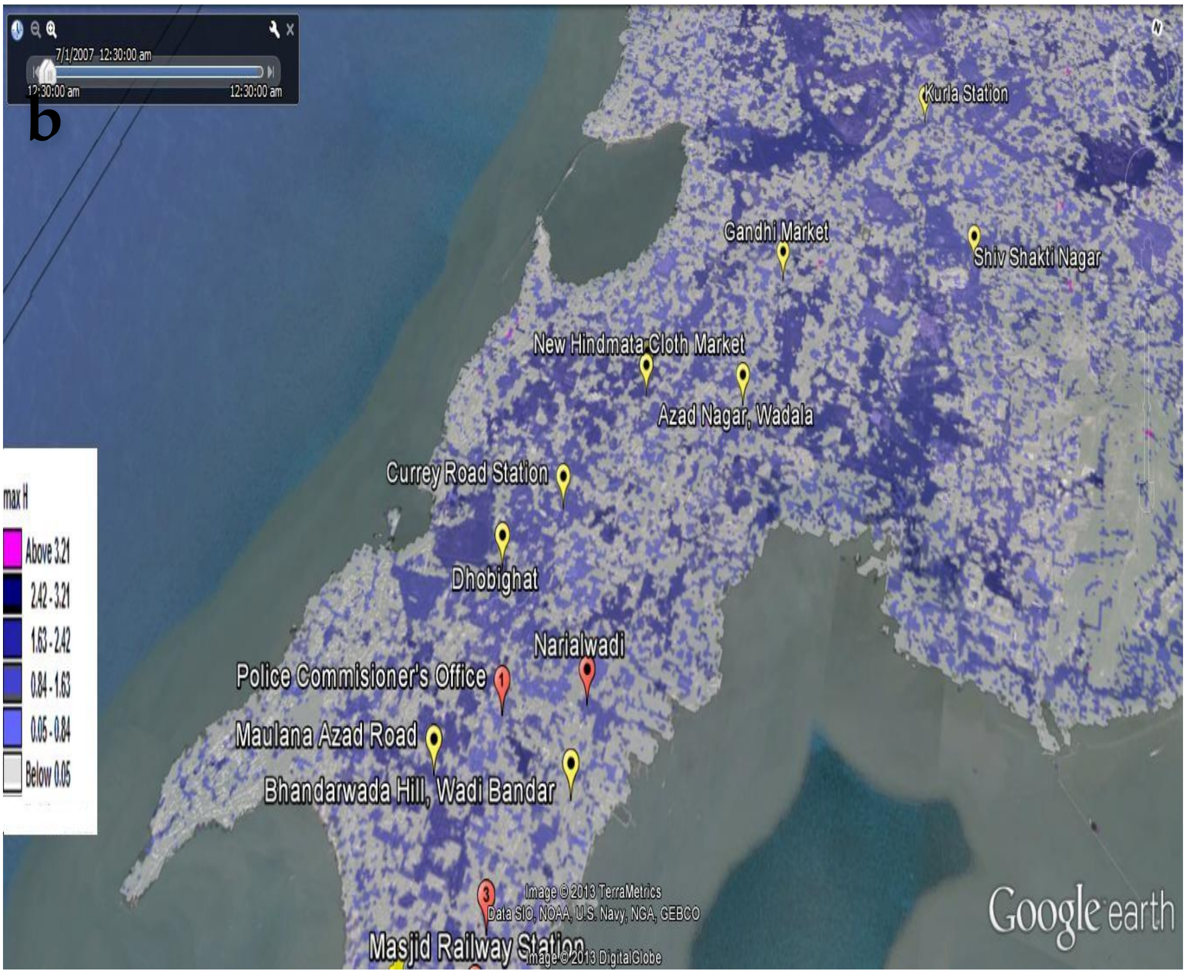


Fig 14 (a) (b) Modelled Flood map overlapped on Google Earth showing the observed flood points in Mumbai in the Greater Mumbai Disaster Management Action Plan report

14.3.6 Conclusions

From the model results the following conclusions can be made

- The results are showing the areas that can be flooded by this localised heavy rainfall, considering the fact that the drainage system is overloaded during high tide. The water level reaches up to 3.5m and above near the creaks and all low lying areas.
- Special attention needed at water logged areas, if the drainage system is not working the flood could be prolong in those areas.
- Several studies were conducted on this extreme event and they also suggests that low lying areas needed attention as these areas has very high flood level and flood risk mitigation practices should be implemented.
- Flooding is not homogenous but it is much localized depending upon the surface gradient and elevation; areas which have flat gradients are likely to get flooded even if the rainfall intensity is not very high.
- Future predictions of rainfall pattern shows increase in extreme events and increase in number of wet days, so the planning for the further infrastructure development should avoids flood prone regions or implement flood risk mitigation practices proactively to mitigate the impacts of flooding.
- Higher intensity with high volume of rainfall results in extreme inland flooding not only in low lying areas but in the main land also.

- Higher intensity with smaller volume of rainfall might causes flooding for shorter period of time and the extent of flooding would be much localized.
- Flooding is highly affected by tides, whenever the high intensity rainfall coincides with high tide Mumbai get flooded because the drainage get chocked and open water outlets get clogged with high level of sea water.

14.4 Adaptation action plan

14.4.1 Adaptation Action: Integrated Flood Management Plan for Mumbai City

Action category: The adaptation action includes strategies that aim at strengthening the storm water drainage network as well as improving the groundwater percolation to avoid flash flooding. It is targeted towards implementation and regulation by the local authorities as well as bottom up approach of community participation.

Rationale: Mumbai Metropolitan Region comprises of two distinct regions. The urban region includes the Greater Mumbai and Suburban district, while the peri-urban includes corporations of Thane, Navi Mumbai, Kalyan-Dombivali, Mira-Bhayandar, Vasai-Virar, Bhiwandi-Nizampur, Ulhasnagar, remaining Municipal Councils including that of Alibaug, Matheran and rest of the Gram Panchayats. The given adaptation plan caters to the Mumbai district (Greater Mumbai and Mumbai Suburban) or Mumbai city as widely known. The city is administered by Municipal Corporation of Greater Mumbai (MCGM) and is highly urbanized.

Geographically, the city is only about 10-15 meters above the sea level[44] and below the high tide level[45]. Large areas of the city are reclaimed such as the Bandstand, Backbay, Cuffe Parade, Mahim Creek, and Bandra Kurla Complex. In addition, many sections of the city are concretized. This leads to the minimal surface water percolation. Several of the natural wetlands within the city are either reclaimed or clogged due to dumping of waste or construction debris. Owing to the given situation, the city is highly vulnerable to floods. MCGM currently has a dedicated storm water drainage department to monitor the storm water drainage network. Likewise, it has also allocated resources and responsibilities to different agencies in the city such the fire brigade department and BEST (Bombay Electric and State Transport) to deploy transport vehicles in event of flood and extreme climatic incidences. The Disaster Management Plan developed by the Government of Maharashtra for Mumbai city has also identified several flood 'hot spots' ward wise. These 'hot spots' include several slum settlements as well as low-lying areas and roads.

Key components of the action:

- Establishing a flood rescue center at each of the flood hot spots already identified by the key authorities.
- Networking the flood rescue centers with other service providers in the city

[44] http://mdmu.maharashtra.gov.in/pages/Mumbai/mumbaiplanShow.php#getdmp

[45] N. Ranger et. al. December, 2010 *An assessment of the potential impact of climate change on flood risk in Mumbai. Springer*

- Using porous asphalt surfaces to increase groundwater recharge or permeability potential.
- Mapping of the identified flood hot spots and sharing the maps with the community so as to include their inputs on possible spots of flooding in their area.
- Training the community on actions to be taken in case of a flood event

Expected outcomes:

Flood rescue centers can provide the required help to the community at the earliest during a flood event. These centers will be equipped with all the possible systems and resources to help evacuate people from the flooded regions. It will also be connected to the other service providers within the city such as the fire brigade department and BEST, which are already appointed by the MCGM to move the affected population to the safest location in minimum time period. These centers would also be linked with the State Disaster Management Department.

By using porous asphalt, not only the groundwater can be recharged, it can also act as an excellent method to avoid water logging problems, especially in the low lying regions. The existing storm water drainage network can be supported by such initiatives to elude water logging issues.

Since, the MCGM has already identified flood hot spots, these spots can be digitally mapped through Geographic Information System (GIS). This map can then be shared with the community members and suggestions could be received on the other possible locations where possible flooding could occur. Likewise, the community could also be trained on the possible actions to be taken in case of a flood incidence, something which is similar to fire drills.

Implementation:

<u>Timeframe</u>

Short Term: 1-2 years	• Mapping of the identified flood hot spots and sharing the maps with the community so as to include their inputs on possible spots of flooding in their area. • Training the community on actions to be taken in case of a flood event
Long Term: 3-5 years	• Establishing a flood rescue center at each of the flood hot spots • Networking the flood rescue centers with other service providers in the city • Using porous asphalt to increase groundwater recharge

<u>Links with ongoing govt. initiatives</u>

- Initiatives taken by the Storm Water Drainage department of MCGM
- Disaster Management Plan developed by the Disaster Management Department of Government of Maharashtra

<u>Nodal Govt. Departments</u>

Departments of MCGM: Storm Water Drainage Department, Rainwater Harvesting Department, Public Works Department

Government of Maharashtra: Disaster Management Department

14.4.2 Adaptation Action: Integrated Flood Management Plan for Suburban and Peri-Urban areas of MMR

Action category: Infrastructure strengthening, disaster risk reduction, focus on urban community

Rationale: Owing to the increasing population and over-crowding of Mumbai city, the population from the city is gradually shifting to the suburban and peri-urban areas. According to the 2011 Census, Thane district is the most populous district of Maharashtra and there is a decrease in the population observed in Mumbai and Mumbai Suburban district. Steady development is also observed in peri-urban areas such as Karjat, Dahanu, Badlapur and so on. For precautionary measures to mitigate flood situations in these areas in future, given the projected climatic scenarios, the following key actions are proposed.

Key components of the action:

- Establishing flood management department in the suburban and peri-urban municipal corporations/ councils of MMR consisting of the following divisions.
  - The storm water drainage division could develop the storm water drainage network, clean-up of the drainage network, maintainance and other related tasks.
  - The rain water harvesting division could look after implementing of rainwater structures in the jurisdiction of the local government body/ authority. This division could also look at the regulation and implementation of permeable surfaces/ roads to increase groundwater percolation and to avoid water logging in association with the public works department.
  - The weather forecast division could disseminate real time weather forecast information in monsoon as a preliminary step to elude flood situations.

  This department could also publish annual flood management reports on the status of storm water management and rain water harvesting to keep a check on the status of the infrastructure.
- Regulating conversion of agriculture and forest land into non-agricultural land for development purpose and increasing tree cover in the region.

Expected outcomes: The flood management departments in corporations and councils would enhance disaster preparedness. Constructing permeable roads and other surfaces can help maintain the groundwater levels in these regions as well as prevent water logging. Regulation on land conversion can help keep a check on the green cover in these regions. Increasing tree cover can help arrest surface run-off as well as soil erosion, thus maintaining soil quality.

Implementation:

Timeframe	**Short-term (1 to 2 years):** Establishing flood management department in the municipal corporations/ councils of MMR; Publishing annual flood management reports; Regulating conversion of agriculture and forest land **Long-term (3 to 5 years):** Increasing tree cover in the region

Links with ongoing govt. initiatives	Similar initiatives and departments in other municipal corporations and councils Disaster Management Plan developed by the Disaster Management Department
Nodal Govt. Depts.	Disaster Management Department and MMRDA

15. Climate change impacts and adaptation in energy and infrastructure sectors

Given the projected increase in temperature, energy demand for cooling is likely to increase in the state in the future, particularly in urban areas like Thane, Pune, Aurangabad, and Nashik, which have a large population, growing development needs, and expanding residential and commercial spaces. Though energy and infrastructure were not identified as a priority sector for adaptation at the formulation stage of this research study, the following recommendations would be win-win options for the state in terms of both climate change adaptation as well as mitigation.

15.1 Recommendations

- Promotion of cleaner forms of energy
- Shift to energy efficient systems to conserve energy
- Climate proofing of new public infrastructure

15.2 Action plan

- Solar rooftop power generation in the urban areas which have large potential in commercial, industrial and residential buildings. Policy support at national and state level is required to reduce the cost of technology so as to facilitate effective implementation.
- Use of biomass based power generation, which will use biomass in efficient way and reduce the fossil fuel (diesel) consumption in DG sets.
- Introduction of policies for promoting usage of hybrid systems (solar and wind) in urban and rural areas. Institutions such as schools can benefit largely from such systems, since they can be independent of the electricity supply from the central grid.
- Use of renewable energy in agriculture processing applications such as cold storages (which are highly energy intensive and crucial for agricultural activities). Solar based small scale cold storage is one technology option that is commercially available as of now.
- Use of innovative applications like solar dryers and solar based pumping and irrigation for agriculture.
- Introduction of policies to encourage generation of renewable energy. One innovative measure is net metering which is a billing mechanism that allows residential or commercial customers who generate solar power to get credit for feeding surplus electricity back to the grid.
- Active promotion of waste-to-energy technologies as they have a dual benefit of power generation and easing the load on waste disposal system of the urban area.
- Climate proofing of new public infrastructure (like bridges, roads, ports, etc) by incorporating additional ranges of temperature, rainfall, and sea level rise into design specifications.

15.2.1 Adaptation Action: Enforcing the construction of Green Roofs in the new peri urban developments in the Mumbai Metropolitan Region, as a measure towards the conservation of local biodiversity

Action category: Urban green space offers a unique landscape that supports a diversity of flora and fauna and provides an ever-expanding human population with direct access to nature and all its benefits. Urban habitats and species are sometimes considered to be less important than their rural counterparts but cities host a surprisingly rich and diverse natural environment. Similarly, Mumbai Metropolitan Region (MMR) also is a host to rich biodiversity with Sanjay Gandhi National Park right in the center of the city. Mumbai Suburban area along with the Greater Mumbai is chocked with settlements, population influx, the ever increasing vertical growth and encroachments upon the crucial habitats for many developmental activities. While the developmental activities in the MMR cannot be denied for the fact that Mumbai is the commercial capital of the country, the rich biodiversity it contains cannot be neglected. **Thus construction of green roofs on the new and the old settlements could be made mandatory by providing due guidance to the developers, planners and municipal authorities for the creation of different plant and animal habitats native to the region.**

Rationale: Mumbai Metropolitan region is experiencing a severe land constraints to accommodate the huge influx of population from the nearby rural as well as semi urban areas. The agriculture lands along with the native biodiversity is confronting extensive encroachments owing to the developmental activities within and around the region. The region is has 10% of land area is under mangroves, mudflats and saltpans which are a home to rich biodiversity. However, in Greater Mumbai, mangrove coverage has reduced by 40% between 1990 and 2001[1] and continues to decline further. The total no. of bird species in Sanjay Gandhi National Park has also reduced from 108 in 2005 to 70 in 2011. Thus there is a continual decline in the biodiversity of the region over the years. Further to this, with the employment opportunities in place, there is a continued population influx in the region leading to more developmental activities and pressures in the peri urban regions. Thus it is proposed to integrate green roof systems in the building designs of new developments as a measure to conserve the native bio-diversity. The concept being primitive, is not only innovative but can significantly contribute in improving the aesthetics as well as the well being of the city landscape while safeguarding the biodiversity of the region. While this is proposed, there requires a clear modification in the Building Bye Laws to integrate this measure and make it mandatory in the upcoming developmental projects as well as for the old and existing one.

Key components of the action:

1. Undertaking detailed assessment of potential of green roof systems in new and large developments in the peri urban areas of MMR.
2. Establishing a committee comprising of architects, planners, engineers and members from the relevant municipal councils and a members of biodiversity conservation societies and organizations to evaluate and implement the green roof concepts.

3. Undertaking pilot construction project of green roof in the new residential/commercial/industrial structures in the peri urban areas under the assistance of municipal authorities and corporations with in the MMR.
4. Undertaking cost benefit analysis for the pilot project and preparing a model prototype for replication in the peri urban areas.
5. Identifying the key species of native plants that could be grown on the terraces of the structures within the structural limitations of the building.

Expected outcomes:

1. Some of the native species which are often lost under developmental activities, especially in the peri urban areas, could be replanted/regenerated on the roof tops of the structures, which are often left unaccessed or unattended.
2. The local trees or plantation often attracts diverse species of birds, native to the region. Thus this interaction could be retained with the help of these roof top plantations while remaining in tandem with the developmental activities, which are unequivocal in the peri urban areas.
3. With the help of the committee set up, which would comprise of the technical experts, the feasibility of the project in terms of its physical, financial as well as social sustainability could be put to test. Once tested, the project could be used as a prototype for replication in the other parts of the cities.
4. The aesthetics of the city/region can see a tremendous uplift and can invite the improved health conditions of the citizens, while keeping up with the pace of development.
5. Concept of urban agriculture and terrace gardening can be promoted through this concept which can contribute in mitigating the urban heat island effect in the core areas.

Implementation:

Timeframe	**Short term:** Feasibility assessment and pilot project in 3 years **Long term:** Covering at least 20% of the structures in the MMR for green roof construction in the next 5 years. Covering 30-40% of both old as well as new constructions in the next 10 years. Bringing into existence stringent policies for terrace gardening and green roofs with the exiting biodiversity conservation policy frameworks.
Links with the ongoing activities	Rules under the **Maharashtra Biological Diversity Act 2002**. Maharashtra State Biodiversity Board and State Biodiversity Management Committee is also established under these rules. These rules address the conservation and management of the State Biodiversity related issues. The rules also aim to establish a Biodiversity Fund to further mobilize conservation activities in the state.
Nodal Government Department	MMR Municipal corporations and councils could be involved. Bombay Natural History Society (BNHS) could be consulted for the specific consultation on local biodiversity of MMR region.

	For construction activities, Mumbai Metropolitan Regional Development Authority and Urban Development Department could be approached. Planning Department, for policies and implementation regarding the green roofs in the peri urban areas.

16. Implementation of MSAAPCC

The Maharashtra State Adaptation Action Plan on Climate Change outlines broad and ambitious strategies for building a climate resilient future for the State while ensuring that it continues on a sustainable development pathway. It will stay abreast with the developments in international negotiations on climate change and India's position, in order to re-assess and fine-tune its own progressive policy framework to ensure adequate, timely and effective action on climate change in the State. The MSAPCC will thus regularly seek expert inputs and stakeholder feedback to make necessary amendments in its approach as required.

16.1 Sector-specific departmental responsibilities

Delivering the Action Plan demands coordinated effort by all key State Government Departments. A summary of sector-specific adaptation recommendations and concerned departments is given in Table 1.

Table 1. Sector-specific adaptation recommendations and concerned departments

Sector	Vulnerable regions	Sector and key adaptation recommendations	Concerned departments
Agriculture	Nashik, Dhule, Ahmednagar, Aurangabad, Gadchiroli and Wardha	• Safeguard farmers against climate risks through improved access to climate services, risk management strategies, and safety nets against climate extremes • Enhance resilience of farming systems through diversified cropping patterns, soil conservation, and value addition • Secure food supply chains	Agriculture Department Irrigation, Water Resources, and Forest Departments India Meteorological Department State agriculture universities and KVKs
Water resources	Origins and catchment areas of river basins	• Conservation and renaturalisation of rivers and water bodies • Enhancement of water storage and groundwater recharge • Improvement of water use efficiency	Urban Development Department Environment Department Water Resources Department Rural Development Department
Health	Coastal Maharashtra and eastern parts of the state	• Enhance monitoring & surveillance for different climate-sensitive diseases and develop health-related climate services and early warning system • Invest in research related to climate change and health • Improve overall health infrastructure and training • Promote community	Health Department

Sector	Vulnerable regions	Sector and key adaptation recommendations	Concerned departments
		surveillance programmes and awareness programmes	
Ecosystems	Northern Western Ghats, and Marathwada, Khandesh and Vidarbha grasslands	• Enhance quality of forest cover and improve ecosystem services • Diversify livelihood options • Promote scientific monitoring and research for improved decision-making	Forest Department
Energy & Infrastructure	Thane, Pune, Aurangabad, Nashik, and other cities	• Promotion of renewable energy and waste to energy • Climate proofing of new public infrastructure	Maharashtra Energy Development Agency Urban Development Department
Cross-sectoral		• Integrate future climate change projections and uncertainties into state disaster management plans and disaster risk reduction strategies. • Incorporate climate change concerns into development plans and land use planning	State Planning Commission

16.2 Mainstreaming climate change into development policies

While specific departments can be identified to take the responsibility for the identified adaptation actions, there is a need to mainstream climate change into the state's development policies across the board.

- Integrate future climate change projections and uncertainties into state disaster management plans and disaster risk reduction strategies. For example, increased number of dry days is projected over south-central Maharashtra and increased intensity of rainfall is projected over northern Maharashtra in the 2030s relative to the baseline for these regions. Such changes from past climate need to be incorporated into the drought management and flood management plans.
- Incorporate climate change concerns into development plans and land use planning. For example if business as usual trends in land use and land cover change continue, there could be increased fragmentation and degradation of forests, making these ecosystems more vulnerable to climate change, as well as the dependent species and livelihoods. Land use zoning and development planning can be oriented to protection and restore such ecosystems and make them more resilient to climate change.

16.3 Public awareness and people's participation

Ensuring adequate public participation is central to the design and implementation of any SAPCC. The Government of Maharashtra will build upon the existing initiatives and launch large scale awareness campaigns engaging community leaders, teachers, youth, women among other stakeholders to ensure that the response to climate change also have local roots.

Effective climate action on adaptation requires general public awareness and community involvement. There is potential for key roles to be played by the women, the youth, NGOs and community leaders. The Government of Maharashtra will launch a comprehensive programme of action that would include awareness campaigns to maximize knowledge sharing at the local level, field based projects to use the power of demonstration, and smart ICT applications. A key requirement for the success of this programme would be partnerships with NGOs, knowledge organizations, and community associations working on climate change issues in India and elsewhere.

- The MSAAPCC would seek to proactively engage women SHGs. These groups can be trained to spread awareness, handle technology demonstrations, and produce dissemination material to communicate climate change in locally relevant ways. The scope of micro-credit financing may be expanded to promote 'green jobs' for rural women – an example would be entrepreneurship in solar home systems and charging stations.
- Young people need to be well-informed about climate change. Education and training programmes can prepare young people to take advantage of new employment opportunities arising from the shift to greener technologies. Special training programs can be organized for school teachers for mainstreaming climate change education in the school curriculum. State as well as District-level events like science exhibitions can have climate change as their main theme. Green Ratings and financial incentives would encourage schools to come up with innovative activities on climate change.
- Community leaders need to be empowered to motivate community members to adopt climate resilient practices in livelihood activities. Local initiatives towards innovative and successful application of climate resilient technologies would need to be recognized and rewarded. The local administration need to be encouraged to partner with such community leaders.
- Grass root level organizations can play a major role in mobilizing people and creating awareness among them. Radio programmes are a potent means of connecting with the people and NGOs can be involved in creating content that is locally relevant. NGOs can help in documenting existing coping strategies of communities and monitor the adaptation interventions of the State. Demonstration projects can be adopted by the NGOs and community organizations to function as 'field labs' on community based adaptation to climate change under specific local circumstances. Knowledge organizations can partner with local NGOs in such initiatives.
- Celebrities may be encouraged to act as Climate Change Ambassadors to spread awareness related to climate friendly lifestyle.

16.4 Knowledge management

Following the mandate of the National Mission on Strategic Knowledge for Climate Change which seeks to build a vibrant and dynamic knowledge management system that would support national action to effectively respond to the objective of ecologically sustainable development, creation of a state level knowledge management centre on climate change is proposed. The Knowledge Management Centre would facilitate flow of information and knowledge between the experts, policy makers and vulnerable communities. Our approach would therefore focus on building and strengthening the knowledge management centre to function as a node for providing accurate and balanced information on climate change. The knowledge management centre would also focus on creating a knowledge repository as well as on improving knowledge access and transfer.

The State Network for Climate Change Assessment would be a network-based programme of the State Government consisting of research institutions and scientists within the state, aided by an advisory council of national experts/institutions. The SNCCA would comprise of core research groups who would undertake scientific assessments on different aspects of climate change.

16.5 Institutional arrangements and implementation

Implementing this ambitious plan requires resources, both technical and financial, for achieving envisaged outcomes within the desired time-frame. The State has several exemplary initiatives in place to address climate change, and the MSAAPCC would leverage these opportunities. For building technical expertise, knowledge partnerships will be forged with various institutes of excellence working on climate change issues in India and overseas. To support the more ambitious plans, additional financial support would be sought from the Government of India and private corporate sources. In addition multilateral and bilateral channels and market-based mechanisms will be explored for supporting action on adaptation to climate change.

The Government of Maharashtra constituted a State Council on Climate Change vide Government Resolution dated 8th July 2011. The Council is chaired by the Chief Minister, with the Deputy Chief Minister acting as Co-Chairman. The members of the Council include the Ministers for Environment, Agriculture, Water Resources, and Rural Development, along with the Chief Secretary. The Council also has experts from research institutions, scientific institutions, corporate sector, and non-governmental organizations.

The implementation of the MSAAPCC will be overseen by a high-level State Steering Committee under the chairmanship of the Chief Secretary. The State Council on Climate Change will guide the Steering Committee in setting priorities and related strategic decision-making. The Department of Environment will be the nodal point for coordination and implementation of the State Action Plan and will be supported by the setting up of a dedicated Climate Change Cell. It is proposed to constitute Task Forces with specific thematic focus (e.g. water, agriculture, forestry and biodiversity) and having high-level representation from all relevant Departments related to the specific theme. The Task Forces would be responsible for identifying the specific implementation agencies to carry out the chosen adaptation actions.

References

Acharya, S S.,2006. Sustainable Agriculture and Rural Livelihoods, Agricultural Economics Research Review, 19, pp 205-217
Adger, W. N. 2006. Vulnerability.Global Environmental Change, 16(3), pp.268-281
Adger, W. N., N. Brooks, G. Bentham, M. Agnew and S. Eriksen 2004.New indicators of vulnerability and adaptive capacity.Norwich, UK: Tyndall Centre for Climate Change Research.
Aggarwal P K (ed). 2009. Global Climate Change and Indian Agriculture. Case Studies from the ICAR Network Project. Indian Council of Agricultural Research, New Delhi-110012, India, 148p.
Alexander, L. V., and Coauthors, 2006, Global observed changes in daily climate extremes of temperature and precipitation. J. Geophys. Res., 111, D05109, doi:10.1029/2005JD006290.
Anand, S., and Amartya Sen, 1994.Human Development Index: Methodology and Measurement, Occasional Paper 12, United Nations Development Programme, Human Development Report Office, New York.
Anna Mclvor, t. S. (2012). coastalresilience.org. Retrieved April 20, 2013 from coastalresilience.org/…/strom-surge-reduction-by-mangroves-report.pdf
Archana Patankar, A. P. (2010). MUMBAI CITY REPORT. Bangkok.
Arunachalam, B. (2005, September 3). Drainage Problem of Brihan Mumbai. Economic and Political Weekly .
Benson, C. 2004. Macro-economic Concepts of Vulnerability: Dynamics, Complexity and Public Policy, in G. Bankoff, G. Frerks and D. Hilhorst, eds, Mapping Vulnerability: Disasters, Development and People, London: Earthscan.
Bhaskaran, B., Jones, R.G., Murphy, J.M. and Noguer, M., 1996, Simulations of the Indian summer monsoon using a nested regional climate model: domain size experiments, Climate Dynamics, 12, 573-587.
Bhuyan, S.J., Mankin, K.R. and Koelliker, J.K. (2003). "Watershed scale AMC selection for hydrologic modeling". Transactions of ASAE 46, 237-244.
Birkmann, J.2006. Indicators and criteria for measuring vulnerability: Theoretical bases and requirements. UNU Times , pp. 55–77
BirldLife International (UK).
Bishop, W., & Catalano, C. (2001). Benefits of Two-dimensional Modelling for Urban Flood. Conference on Hydraulics in Civil Engineering . Barton: A.C.T.: Institution of Engineers, Australia.
Blaikie, P., T. Cannon, I. Davis & B. Wisner, 1994.At Risk: Natural Hazards, Peoples' Vulnerability and Disasters, London: Routledge.
BNHS undated. Important Bird Areas in Maharashtra, Bombay Natural History Society.
Cannon, T.,1994.Vulnerability Analysis and the Explanation of 'Natural' Disasters. In Disasters, Development and Environment, edited by A. Varley.pp. 13-29 John Wiley & Sons :New York
Census of India, Office of the Registrar General and Census Commissioner, India.Census Data 2001. Available at: http://www.censusindia.net/ . Retrieved 28 July 2009.
Chatterjee A (1998) Simulating the impact of increase in carbon dioxide and temperature on growth and yield of maize and sorghum. M.Sc Thesis, Division of Environmental Sciences, IARI, New Delhi

Chatterjee, C., Jha, R., Lohani, A.K., Kumar, R. and Singh, R. (2001). “Runoff curve number estimation for a basin using remote sensing and GIS”. Asian pacific remote sensing and GIS journal, 14, 1-7.

Chaturvedi R K, Gopalakrishnan R, Jayaraman M. Bala G., Joshi N. V., Sukumar R., and Ravindranath N. H. 2011. Impact of climate change on Indian forests: a dynamic vegetation modelling approach. Mitig Adapt Strategy Globe Change (2011) 16:119–142

Chitale. (2006). Fact Finding Committee on Mumbai Floods. mumbai: Govt. of Maharashtra.

Chow, V.T., Maidment, D.K., Mays, L.W. (2002), “Applied Hydrology”. McGraw-Hill Book Company, New York, USA.

Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

CMFRI (2005b) Marine Fisheries Census 2005, - Maharashtra, Published by Central Marine Fisheries Research Institute, Government of India, Ministry of Agriculture, Department of animal Husbandry, Dairying and Fisheries, New Delhi, 319 pages.

conservation. Indian Bird Conservation Network: Bombay Natural History Society and

Cooper P, Rao K P C, Singh P, Dimes J, Traore P S, Rao K, Dixit P, and Twomlow SJ. 2009. Farming with current and future climate risk: Advancing a ‘Hypothesis of Hope’ for rainfed agriculture in the semi-arid tropics. Journal of SAT Agricultural Research 7:1-19.

Corfee-Morlot, S. H. (2010, December 07). Understanding climate change impacts, vulnerabilityand adaptation at city scale: an introduction. Springer Science+Business Media , 1-12.

Cutter, S. L., L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, and J. Webb 2008. A place-based model for understanding community resilience to natural disasters.Global Environmental Change 18(4), pp. 598-606.

Das A., Krishnaswamy J, Bawa K. S., Kiran M.C., Srinivas V., Samba Kumar N., Karanth K. U. 2006. Prioritisation of conservation areas in the Western Ghats, India. Biological Conservation 133 (2006) 16-31.

Daw, T.; Adger, W.N.; Brown, K.; Badjeck, M.-C. 2009. Climate change and capture fisheries: potential impacts, adaptation and mitigation. In K. Cochrane, C. De Young, D. Soto and T. Bahri (eds). Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO Fisheries and Aquaculture Technical Paper.No. 530. Rome, FAO. pp.107-150.

DHI. (2011). MIKE 21 Flow Model Hydrodynamic Module Scientific Documentation.

DHI. (2011). MIKE 21 FLOW MODEL Hydrodynamic Module User Guide.

Downing, T.E., Butterfield, R., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y., Stephen, L., 2001. Climate Change Vulnerability: Linking Impacts and Adaptation. University of Oxford: Oxford

Elhakeem, M. and Papanicolaou, A. N. (2009) “Estimation of the runoff curve number via direct rainfall simulator measurements in the state of Iowa”, Water Resour. Manag., 23, 2455–2473.

Ericksen P, Thornton P, Notenbaert A, Cramer L, Jones P, Herrero M. 2011. Mapping hotspots of climate change and food insecurity in the global tropics. CCAFS Report no. 5.

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark.
Esty, D.C., M. Levy, T. Srebotnjak, and A. de Sherbinin.2005. Environmental Sustainability Index: Benchmarking National Environmental Stewardship. New Haven, CT: YaleCenter for Environmental Law & Policy
Fageria N. K. (1992). Maximizing Crop Yields. Marcel Dekker Incorporation, New York. Retrieved from http://books.google.co.in/books?id=NbPMD99XIkEC&pg=PA242&lpg=PA242&dq=rainfall+requirement+of+mung+bean&source=bl&ots=f8l5jUCvFU&sig=a_hMFd9UTAmt-1kcahbZrhiuQLo&hl=en&sa=X&ei=ITffU-_qE9SdugS0mIDICg&sqi=2&ved=0CCoQ6AEwAg#v=onepage&q=rainfall%20requirement%20of%20mung%20bean&f=false
FAO. 1991. A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. http://www.fao.org/docrep/u3160e/u3160e04.htm
FEMA. (2009). Mapping the Zone: Improving Flood Map Accuracy. FEMA. National Academy of Sciences.
FICCI, 2011. Making Maharashtra the Fruit Bowl of India, Food & Agribusiness Strategic Advisory and Research Group (FASAR)
FICCI, 2011. Making Maharashtra the Fruit Bowl of India, Food & Agribusiness Strategic Advisory and Research Group (FASAR)
floods, F. f. (2006). Fact finding committee on Mumbai floods. Mumbai: Government of Maharashtra.
Forest Survey of India (2013) State of Forest Report
Fussel, H M., 2007. Vulnerability: A generally applicable conceptual framework for climate change research. Global Environment Change, 17, pp.155-167
GoI. 2012. India's Second National Communication to the United Nations Framework Convention on Climate Change. New Delhi: Ministry of Environment and Forests.
GoM , 2010, Maharashtra Agricultural Competitiveness Project (Macp) Project Implementation Plan (Pip), World Bank.
GoM. (2005). Maharashtra floods 2005: relief and rehabilitation. Mumbai: Government of Maharashtra.
Goswami B.N., Venugopal V., Sengupta D., Madhusoodanan M.S. & Xavier Prince K., 2006: Increasing trend of Extreme Rain Events over India in a Warming Environment, Science, 314, 5804, 1 December, 1442-1445.
Government of Maharashtra, 2010. Agro-Industrial Policy 2010.
Gupta, K. (2007). Urban flood resilience planning and management and lessons for the future: a case study of Mumbai, India. Urban water journal , 4, 183-194.
Hahn, M.B., Riedere, A.M, & Foster.S.O 2009. The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change: A case study in Mozambique. Global Environment Change, 19, pp.74-88
Harmonized World Soil Database (version 1.2). (2012) FAO/IIASA/ISRIC/ISSCAS/JRC. FAO, Rome, Italy and IIASA, Laxenburg, Austria.
Hebbar, K.; Venugopalan, M.; Prakash, A.; Aggarwal, P.Simulating the impacts of climate change on cotton production in India Climatic Change, Volume 118, Numbers 3-4, June 2013 , pp. 701-713(13)
Hinkel, J. 2011.Indicators of vulnerability and adaptive capacity'': Towards a clarification of the science–policy interface. Global Environment Change.21, pp.198-208

ICRISAT. 2008. Adaptations to and Mitigation of Climate Change in the Semi-Arid Tropics: ICRISAT's Operational Research Strategy 2008–2015. Patancheru: International Crops Research Institute for the Semi-Arid Tropics.
ICRISAT. 2013. Fertilizer microdosing: Boosting production in unproductive lands. Patancheru: International Crops Research Institute for the Semi-Arid Tropics.
IMD. 2012. Trends and variability of monthly, seasonal and annual rainfall for the districts of Maharashtra and spatial analysis of seasonality index in identifying the changes in rainfall regime. National Climate Centre Research Report 1/2012. Pune: India Meteorological Department.
INCAA 2010. Climate change and India: a 4x4 assessment. A sectoral and regional analysis for 2030s. INCAA Report 2, November 2010.
INCAA Report#2. Climate change and India: A 4X4 assessment – A sectoral and regional analysis for 2030s, November 2010.
Indo-UK research programme on the impacts of climate change on India, vulnerability assessment of Madhya Pradesh, September, 2012, Submitted to DECC, MoEF and ERM
IPCC (2007) Climate change 2007: the physical science basis.In: Solomon S, Qin D, Manning M, Chen Z and others (eds) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Islam, M.Z and Rahmani, A.R (2004) Important Bird Areas in India Priority Sites for
J. KAMINI, S. C. (2004). SPATIO-TEMPORAL ANALYSIS OF LAND USE IN URBAN MUMBAI - USING MULTI-SENSOR SATELLITE DATA AND GIS TECHNIQUES. Journal of the Indian Society of Remote Sensing , 34, 7-10.
Jat R A, Dungrani R A, Arvadia M K, Sahrawat K L. 2012. Diversification of rice (Oryza sativa L.) based cropping systems for higher productivity, resource-use efficiency and economic returns in South Gujarat of India. Archives of Agronomy and Soil Science 58(6): 561-572.
K Boomiraj, Suhas P Wani and PK Aggarwal, Impact of climate change in dryland sorghum in India,TNAU-ARS, ICRISAT, IARI, 2011.
K. Vinod Kumar, V. M. (2012). Coastal circulation along the central west coast of India during cyclone Phyan: measurements and numerical simulation. Nat Hazards , 64.
Kaly, U., L. Briguglio, H. McLeod, S. Schmall, C. Pratt, and R. Pal. 1999.Environmental vulnerability index (EVI) to summaries national environmental vulnerability profiles. SOPAC Tech. Rep. 275.Suva, Fiji: South Pacific Applied Geoscience Commission.
Kaly, U., Pratt, C., Howorth, R., 2002.A framework for managing environmental vulnerability in Small Island Developing States.Development Bulletin, 58, pp.33–38.
Kanade R, Tadwalkar M., Kushalappa C. and A. Patwardhan 2008. Vegetation composition and woody species diversity at Chandoli National Park, northern Western Ghats, India. Current Science, Vol. 95, No. 5, 10 September 2008
Kothawale, D.R., Revadekar, J.V. and Rupa Kumar, K., 2010, Recent trends in pre- monsoon daily temperature extremes over India, Journal of Earth System Science, 119(1), 51-65.

Kreibich, H. e. (2009). Is flow velocity a significant parameter in flood damage modelling? Natural Hazards , 10, 1679-1692.
Krishnamurthy, C.K.B., Lall, U. and Kwon, H., 2009, Changing frequency and intensity of rainfall extremes over India from 1951 to 2003, Journal of Climate, 22, 4737-4746.
Luo Q. (2011). Temperature thresholds and crop production: a review. Springer. Retrieved from http://www.locean-ipsl.upmc.fr/~ESCAPE/luo2011.climaticchange.pdf
MoEF, 2010: Climate Change and India: A 4x4 Assessment. Indian Network for Climate Change Assessment Report 2, Ministry of Environment & Forests, Government of India.
Moss, R. H., E. L. Malone, and A.L. Brenkert2002. Vulnerability to climate change: A quantitative approach. Joint Global Change Research Institute
Moss, R.H., Malone, E.L., Brenkert, A.L., 2002. Vulnerability to climate change: a quantitative approach. Prepared for the US Department of Energy
Mukherji, S. S. (2005, September 3-9). Emerging Cityscapes and Environmental Issues. Economic and Political Weekly , pp. 3905-3909.
NASA, O. (2013). NASA Observatory. Retrieved January 30, 2013 from http://earthobservatory.nasa.gov/IOTD/view.php?id=5711
Nguyen..N.V. "Global Climate changes and Food insecurity in FAO, International Rice Commission Part 1, Overview, Page no.27.
Nicola Ranger, S. H.-M. (2010, December 7). An assessment of the potential impact of climate change on flood risk in mumbai. Climate Change , 139-167.
O'Brien ,K., Leichenkob, R., Kelkar,U., Venemad,H., Aandahla, G., Tompkins, H., Javed, A., Bhadwal, S., Bargd, S., Nygaarda,L and West, J. 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India, Global Environment Change, 14, pp. 303–313
O'Brien, K.L., Eriksen, S., Schjolden, A., Lygaard, L., 2004. What's in a word? Interpretations of vulnerability in climate change research. CICERO Working Paper 2004:04, Oslo: Norway
OECD. (2008). Competitive Cities and Climate Change. In V. C. Berkeley (Ed.), 2nd Annual Meeting of the OECD Roundtable of Mayors and Ministers for Urban Development (pp. 1-197). Milan: ISPI - Istituto per gli Studi di Politica Internazionale.
Online.Available at :http://ageconsearch.umn.edu/bitstream/57758/2/Pres-address-1.pdf
P. Krishnan , D.K. Swain , B. Chandra Bhaskar , S.K. Nayak , R.N. Dash. Impact of elevated CO2 and temperature on rice yield and methods of adaptation as evaluated by crop simulation studies. Agriculture, Ecosystems and Environment 122 (2007) 233–242
Panigrahy R. K., Kalel M. P., Dutta U., Mishra A., Banerjee B., Singh S. 2010. Forest cover change detection of Western Ghats of Maharashtra using satellite remote sensing based visual interpretation technique. Current Science, Vol. 98, No. 5, 10 March 2010
Peterson TC, Folland C, Gruza G, Hogg W, Abdallah M, Plummer N., 2001, Report on the activities of the working group on climate change detection and related rapporteurs. ICPO Publication Series no. 48, World Meteorological Organization, Geneva.
Planning Commission, 2007. Report of the Working Group on Horticulture, Plantation Crops and Organic Farming for the XI Five Year Plan (2007-12), Government of India
Planning Commission, 2007. Report of the Working Group on Horticulture, Plantation Crops and Organic Farming for the XI Five Year Plan (2007-12), Government of India
Prescott-Allen, R. 2001.The Wellbeing of Nations.WashingtonD.C.: Island Press.
R. B. Bhagat, M. G. (2006). Mumbai after 26/7 Deluge: Issues and Concerns in Urban Planning. Population and Environment , 27, 337-349.

R.K. Jenamani, S. B. (2006). Observational/forecasting aspects of the meteorological event that caused a record highest rainfall in Mumbai.
Rajeevan, M., Bhate, J., Kale, J.D. and Lal, B., 2006, High resolution daily gridded rainfall data for the Indian region: Analysis of break and active monsoon spells, Current Science, 9(3), 296-306.
Ranuzzi A and Srivastava R. 2012. Impact of climate change on agriculture and food security. ICRIER Policy Series No. 16. Delhi: Indian Council for Research on International Economic Relations.
Ranwa 1993. Biodiversity Hotspots Conservation Programme, Western Ghats of Maharashtra. Basis for Proposals. Prepared for WWF-India by Ranwa, Pune Team led by Mr Utkarsh Ghate.
Ravindranathan, R., (no year). Climate change and forests: Status of science, policy and research. Indian Institute of Science.
Rupa Kumar, K., Sahai, A. K., Krishna Kumar, K., Patwardhan, S.K., Mishra, P.K., Revadekar, J.V., Kamala, K. and Pant, G.B., 2006, Higher-resolution climate change scenarios for the India for the 21st century, Current Science, 90(3), 334-345.
S.D. Singh, Bidisha Chakrabarti and P.K. Aggarwal, Impact of elevated temperature on growth and yield of some field crops. Global Climate Change and Indian Agriculture, Case studies from the ICAR network, Edited by P.K. Aggarwal, 2009.
S.D. Singh, Bidisha Chakrabarti and P.K. Aggarwal, S. Nagarajan and Madan Lal, Impact of elevated carbon dioxide on growth and yield of leguminous crops. Global Climate Change and Indian Agriculture, Case studies from the ICAR network, Edited by P.K. Aggarwal, 2009.
Shankar K R, Nagasree K, Venkateswarlu B, Maraty P. 2011. Constraints and Suggestions in Adopting Seasonal Climate Forecasts by Farmers in South India. The Journal of Agricultural Education and Extension 17(2): 153-163.
Sherbinin A., S. (2007). The Vulnerability of Global Cities to Climate Hazards, Environment and Urbanization. Sage Publications on behalf of International Institute for Environment and Development , 19, 1.
Srivastava, A.K., Rajeevan, M. and Kshirsagar, S.R., 2009, Development of a high resolution daily gridded temperature data set (1969-2005) for the Indian region, Atmospheric Science Letters, 10, 249-254, DOI: 10.1002/asl.232.
Steadman, R.G., 1979, The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. J. Appl. Meteor., 18, 861-873.
Sullivan, C. and J. Meigh 2005. Targeting attention on local vulnerabilities using an integrated index approach: The example of the climate vulnerability index.Water Science & Technology 15 (5), pp.69-78.
Tadwalkar M., Joglekar A., Mhaskar M., Kanade R., Chavan B., Watve A., Ganeshaiah K., N. and Patwardhan A. 2012. Dispersal Modes Of Woody Species From The Northern Western Ghats, India. Tropical Ecology 53(1): 53-67, 2012.
Tebaldi C, Hayhoe K, Arblaster JM, Meehl GE., 2006, Going to the extremes: an intercomparison of model-simulated historical and future changes in extreme events. Clim Change 79:185–211.
Thompson, Bell and Butler, 2001.
Tietze, U., Siar, S., Upare, S. M. &Upare, M.A. 2007. Livelihood and micro-enterprise developmentopportunities for women in coastal fishing communities in India – Case studies of Orissa andMaharashtra.FAO Fisheries Circular.No. 1021. Rome, FAO. 69 p.

Torresan, S., A. Critto, M.D Valle, N. Harvey, and A. Marcomini 2008. "Assessing coastal vulnerability to climate change: Comparing segmentation at global and regional scales.Sustainability Science 3(1), pp. 45-65.
Turner, A.G. and Slingo, J.M., 2009, Uncertainties in future projections of extreme precipitation in the India monsoon region, Atmospheric Science Letters, 10, 152-158.
UNDP, 1990.Human Development Report 1990. New York: OxfordUniversity Press.
USDA, Soil Conservation Service (1985), "National Engineering Handbook", USA.
V Geethalakshmi, K. Palanisamy, P.k. Aggarwal and A. Lakshmanan, Impacts of climate on rice, maize and sorghum productivity in Tamil Nadu, Tamil Nadu Agricultural University and Indian Agricultural Research Institute, . Global Climate Change and Indian Agriculture, Case studies from the ICAR network, Edited by P.K. Aggarwal, 2009.
Van Vuuren, D. P., et al., 2011b: The representative concentration pathways: An overview, Clim. Change, 109, 5–31.
Vision 2025, CICR Perspective Plan, Central Institute for Cotton Research, Nagpur, ICAR
Vivekanandan, .2011.Climate Change and Indian Marine Fisheries. Central Marine Fisheries Research Institute, Niseema Printers & Publishers: Kochi
Vivekanandan, E, Rajagopalan, M, Pillai, N G K , 2009. Recent trends in sea surface temperature and its impact on oil sardine. In: Aggarwal P K (Ed) Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change, Indian Council of Agricultural Research, New Delhi.
Wank and Hartnack, 2006.
Watkiss, A. H. (2011). Climate Change Impacts and Adaptation in Cities: A Review of the Literature. Opus: University of Bath Online Publication Store , 13-49.
Yadav, R.K., Rupa Kumar, K. and Rajeevan, M., 2010, Climate change scenarios for Northwest India winter season, Quaternary International, 213, 12-19.

Web Links
http://www.epa.gov/naturalevents/flooding.html [Accessed, 15th December 2012]
http://ks.water.usgs.gov/waterwatch/flood/definition.html [Accessed, 15th December 2012]
http://www.shvoong.com/exact-sciences/503149-reason-mumbai-heavy-rainfall-event/#ixzz2Gbpzif1Z [Accessed, 15th December 2012]
http://news.bbc.co.uk/2/hi/south_asia/4717999.stm [Accessed, 15th December 2012]
http://www.shvoong.com/exact-sciences/503149-reason-mumbai-heavy-rainfall-event/ [Accessed, 15th December 2012]
http://www.wxtide32.com/ [Accessed, 15th October 2013]
www.mumbaimonsoon.com [Accessed, 15th October 2013]